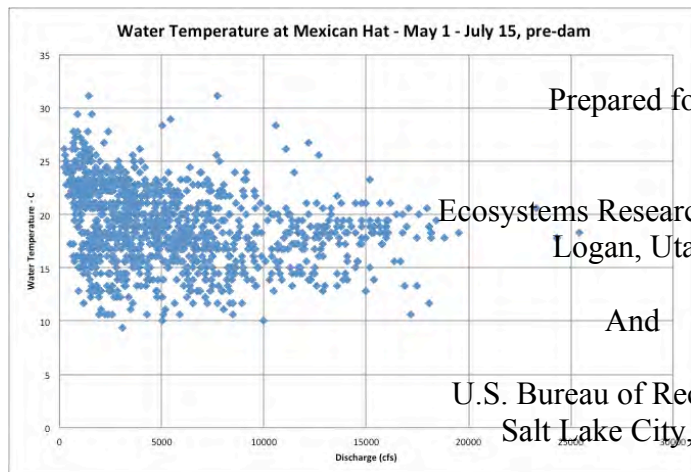


**FINAL**

**Retrospective analysis of water temperature data and larval and young of year fish collections in the San Juan River downstream from Navajo Dam to Lake Powell Utah**



Prepared by:

William J. Miller

And

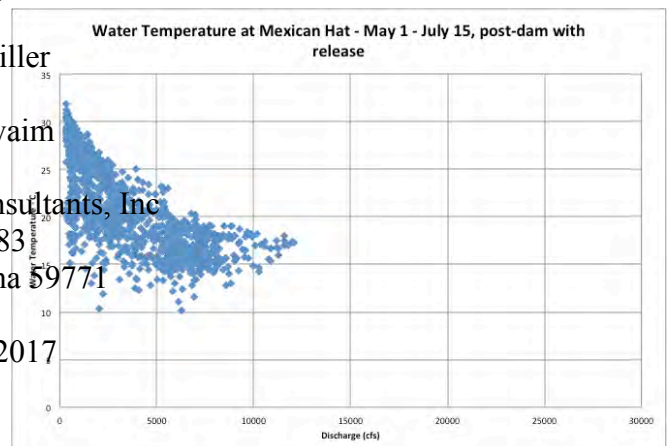
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February 14, 2017



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## Executive Summary

Miller Ecological Consultants conducted a retrospective analysis of existing San Juan River water temperature datasets and larval fish data. Water temperature data for all years available were evaluated in conjunction with the timing and number of larvae captured in the annual larval fish monitoring surveys that are required by the San Juan River Basin Recovery Implementation Program (SJRBRIP) Long Range Plan. Under the guidance of the SJRBRIP, Navajo Dam experimental releases were conducted and evaluated from 1992-1998. After this research period, the SJRBRIP completed the flow recommendations. The SJRBRIP established flow recommendations for the San Juan River designed to maintain or improve habitat for endangered Colorado Pikeminnow *Ptychocheilus lucius* and Razorback Sucker *Xyrauchen texanus* by modifying reservoir release patterns from Navajo Dam (Holden 1999). The flow recommendations were designed to mimic the natural hydrograph or flow regime in terms of magnitude, duration and frequency of flows. Water is released from the deep hypolimnetic zone of the reservoir, which results in water temperatures that are cooler than natural, pre-dam conditions.

Water temperatures in the San Juan River have been monitored and recorded at several locations as part of the SJRBRIP since 1992. The Navajo Dam release has a clear temperature depression effect on temperatures in the San Juan River as far downstream as Mexican Hat, a distance of 173 river miles (Miller and Swaim 2013). While the impacts of the temperature depression are unknown, there was concern that the sudden change in temperature could disrupt Razorback Sucker and Colorado Pikeminnow spawning or reduce hatching success and larval survival due to slower growth rates at lower water temperatures.

The objective of this retrospective analysis was to determine if there are any linkages between the water temperature regime of the San Juan River below Navajo Dam and the timing and number of fish larvae that could be determined from the monitoring data.

We used existing data for the synthesis of water temperature and larval fish collections. Water temperature data were obtained from the San Juan River Water Temperature Database and USGS records. We used the USGS gage at Bluff (also known as Mexican Hat) as the point of comparison for water temperature since it has the longest and most complete water temperature data set. It also has the only pre-dam data for water temperature. Larval fish data were obtained from the San Juan River monitoring database or individual San Juan River monitoring project reports. Data for both water temperature and larval fish collections were analyzed using standard exploratory statistics and more advanced statistical analysis using R statistical software (R Development Core Team 2013).

Mean pre-dam flows peaked at approximately 7500 cfs in early June. Maximum pre-dam flows peaked at approximately 25,000 cfs and were frequently above 15,000 cfs. In contrast, for the post-dam period, mean flows peaked at less than 5000 cfs and maximum flows were almost never above 15,000 cfs. The pre-dam comparison shows numerous days with discharge greater than 5,000 cfs and water temperature equal to or greater than 20°C. There are also numerous days with greater than 10,000 cfs discharge. Post-dam without a specified peak release, there are

still numerous days with flows greater than 5,000 cfs and water temperatures equal to or greater than 20°C. Maximum discharge post-dam is limited to approximately 12,500 cfs. For the post-dam period with spring releases there are very few days when water temperature exceeds 20°C and discharge is greater than 5,000 cfs. For most of the days when flow is greater than 5,000 cfs the water temperature is less than 20°C.

Water temperature depression in the San Juan River varies by year and the proportion of flow attributed to the San Juan River and Animas River. In years where the release from Navajo Dam is larger than the flow from the Animas River, the water temperature shows a distinct depression. When the Animas River provides the majority of the flow, the water temperature does not show a distinct water temperature depression. Water temperature can be reduced by as much as 8°C at Mexican Hat when a large proportion of the discharge comes from Navajo Dam. This amount of water temperature depression could be an impact to the endangered species.

Larval density for Razorback Sucker varied by year but was not correlated with water temperature depressions. The timing of larval collections did not coincide with depressions in water temperature in the San Juan River in most years. Larval seining in the 2000s was conducted on a weekly basis and usually occurred both before and after runoff. The larval collections did detect reproduction by both Colorado Pikeminnow and Razorback Sucker, however, no correlation between water temperature and larval density of either species could be detected. Previous research on both species suggests that altered water temperature regimes due to dam releases could be detrimental to both species. It is unknown if there the water temperature depression caused by releases from Navajo Reservoir impact growth or survival of either species.

In summary, analysis of temperature data showed that, for the San Juan River at Mexican Hat, post-dam temperatures were warmer than pre-dam temperatures throughout early spring and late summer and were the result of reduced flows. Water temperatures at Mexican Hat were cooler with releases than without releases between May 15 and June 20. Since the mid-May to mid-June period coincides with the typical release period, we conclude that the experimental releases do have a temperature depression effect that can be detected as far downstream as Mexican Hat. Flows from the Animas River can moderate the effect of coldwater releases from Navajo Dam.

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## INTRODUCTION

Miller Ecological Consultants conducted a retrospective analysis of existing San Juan River water temperature datasets and larval fish data. Water temperature data for all years available were evaluated in conjunction with the timing and number of larvae captured in the annual larval fish monitoring surveys that are required by the San Juan River Basin Recovery Implementation Program (SJRBRIP) Long Range Plan.

The SJRBRIP established flow recommendations for the San Juan River designed to maintain or improve habitat for endangered Colorado Pikeminnow *Ptychocheilus lucius* and Razorback Sucker *Xyrauchen texanus* by modifying reservoir release patterns from Navajo Dam (Holden 1999). The flow recommendations were designed to mimic the natural hydrograph or flow regime in terms of magnitude, duration and frequency of flows. A natural flow regime (one that existed before human intervention) has a large amount of variability in flow and is dominated by spring snowmelt runoff with low late summer and fall base flows (Holden 1999).

Under the guidance of the SJRBRIP, Navajo Dam experimental releases were conducted and evaluated from 1992-1998. After this research period, the SJRBRIP completed the flow recommendations. Modifications to reservoir operations that mimic the natural hydrograph would assist in conserving endangered fish in the San Juan River downstream from Farmington, New Mexico, while still allowing water development to proceed in the San Juan River Basin. The Bureau of Reclamation (BOR) (2006) evaluated the potential impacts of implementing the recommendations and agreed to change Navajo Dam and Reservoir operations, which were primarily focused on meeting irrigation needs and providing flood control. Water is released from the deep hypolimnetic zone of the reservoir, which results in water temperatures that are cooler than natural, pre-dam conditions.

Colorado Pikeminnow adults were documented in the San Juan River at the approximate location of Navajo Dam prior to construction of the dam (Koster 1960). The San Juan River was treated with rotenone from the reservoir pool downstream to approximately Farmington, New Mexico prior to closure of the dam (Olson 1962). The purpose was to remove the existing fish species and restock with game species. Colorado Pikeminnow were reported by Olson as one species observed in the dead fish after the treatment. Colorado Pikeminnow and Razorback Sucker were present in low numbers in the San Juan River and the San Juan arm of Lake Powell after construction of Navajo Dam (Meyer and Moretti 1988, Platania 1990, Platania et al. 1991, Roberts and Moretti 1989). Colorado Pikeminnow young of the year were captured post-dam and prior to the specified peak flow releases.

Water temperatures in the San Juan River have been monitored and recorded at several locations as part of the SJRBRIP since 1992. Miller Ecological Consultants took over monitoring duties in fall 2011. During this first year of data collection (October 2011 to October 2012), we observed that the Navajo Dam release depressed water temperatures in the San Juan River as far downstream as Mexican Hat, a distance of 173 river miles (Miller and Swaim 2013). While the impacts of the temperature depression are unknown, there was concern that the sudden change in temperature could disrupt Razorback Sucker spawning or reduce hatching success and larval survival due to slower growth rates at lower water temperatures. This concern has also been expressed in the Upper Colorado and Green Rivers (Kaeding et al. 1986, Kaeding and Osmundson 1988, Muth and Nesler 1993, Muth et al. 2000). Bestgen et al. (2011) synthesized 18 years of data regarding Razorback Sucker spawning in the Green River and found that spawning occurs earlier when the Green River warms earlier and later when the river warms later. They suggested that rising water temperatures may be a more important environmental cue for spawning than increasing flow levels. Furthermore, they stated that “given the importance of water temperature on initiating reproduction in razorback sucker, ...it is reasonable to consider whether reservoir releases play a role in delaying spawning by razorback suckers in the middle Green River.” In some years, higher flows are released from Flaming Gorge Dam in early spring to make space in the reservoir for incoming flows. Bestgen et al. (2011) postulated that “if those flows are abnormally cold or cold because the abnormally high volume does not allow for warming as it proceeds downstream, development of gametes by razorback suckers could be delayed.”

The objective of this analysis was to determine if there are any linkages between the water temperature regime of the San Juan River below Navajo Dam and the timing and number of fish larvae that could be determined from the monitoring data. The analysis could then be used in evaluation of the review of flow recommendations and potential impacts of water temperature depression on native fish larvae.

## METHODS

We used existing data for the synthesis of water temperature and larval fish collections. Water temperature data were obtained from the San Juan River Water Temperature Database and USGS records. Larval fish data were obtained from the San Juan River monitoring database or individual San Juan River monitoring project reports.

Data for both water temperature and larval fish collections were analyzed using standard exploratory statistics and more advanced statistical analysis using R statistical software (R Development Core Team 2013). Average, maximum, and minimum daily water temperatures were calculated for each calendar day from April 1 through August 31 for each year of data. The

daily values were then summarized into average, maximum and minimum values for April 1 through August 31 across all years. The April 1 through August 31 time period brackets the runoff and dam release periods. The retrospective analysis was separated into three general time periods for comparison of water temperatures; pre-dam( 1945-1962), post-dam (1963-1976) and post-dam with flow release (1992-2014) based on data availability.

The next step in the analysis was to describe the temperature regime of the San Juan River at Mexican Hat after completion of Navajo Dam for years in which experimental releases occurred and make comparisons to those years in which no experimental release occurred. There were no releases in 1981-1991, and in 2002, 2003, 2004, 2010 and 2014. Releases occurred in 1992-2001, from 2005 – 2009 and in 2011 and 2012. For each calendar day from April through August, the mean, minimum and maximum average daily temperatures were calculated.

Larval fish collection data were summarized for drift net sampling (1993-2001) and larval seining (2003-2014). Drift net data were available from two stations, Mexican Hat and Four Corners. Larval seining data were available from various locations on the San Juan River from Shiprock, New Mexico downstream to Mexican Hat, Utah.

Each of the years from 2003 to 2014 was grouped into one of three categories: No Release, Release but No Temperature Depression and Release & Temperature Depression (the temperature depression refers to temperatures at Mexican Hat). The years of 2002, 2003, 2004, 2010, 2013 and 2014 are within the No Release category. The years of 2005, 2008 and 2011 are within the Release but No Temperature Depression category because either there was no temperature depression or because the depression was due to Animas River temperatures and not the release. The years of 2006, 2007, 2009 and 2012 were placed into the Release & Temperature Depression category. We tested for differences in temperature and fish density between the three categories. Differences were tested using single-factor analysis of variance (ANOVA; R Development Core Team 2013).

## **RESULTS**

### **TEMPERATURE REGIME SUMMARY**

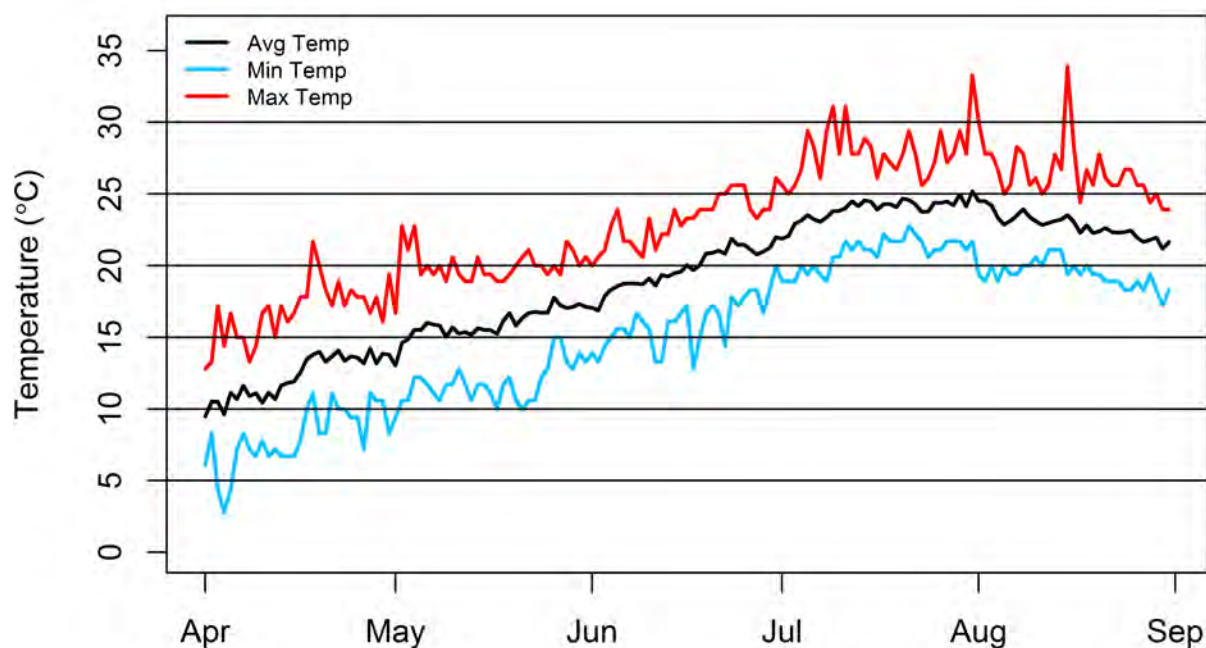
#### **Pre-Dam vs. Post-Dam Comparisons**

The first step in the analysis was to describe the temperature regime of the San Juan River prior to completion of Navajo Dam (1963) to gain an understanding of water temperature patterns under more natural conditions. The only water temperature data available prior to 1963 are from USGS gage 09379500, the San Juan River near Bluff, Utah (which will be referred to as the San

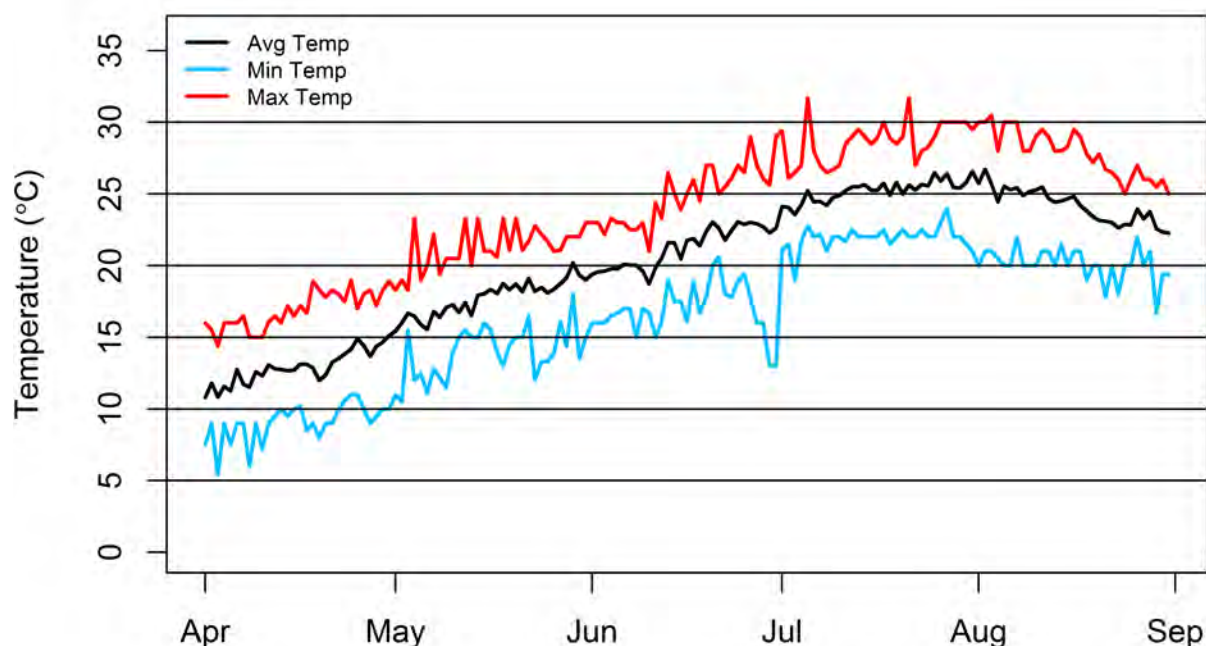


Juan River at Mexican Hat for this report) . This location is within the study area of the larval fish surveys and thus was deemed appropriate for this analysis. Instantaneous temperatures were collected from 1945 through 1976 and average daily temperature data are available from 1981 to present. No data were available from 1977 through 1980. Although instantaneous data measurements do not give a complete picture of temperature conditions, the data do give an indication of the range of temperatures observed under more natural conditions.

To maintain consistency in the type of data used, pre- and post-dam comparisons are limited to the instantaneous data since these were the only data available prior to Navajo Dam completion. Therefore, pre-dam data were those collected between 1945 and 1962 and post-dam data were those collected between 1963 and 1976. Average pre-dam temperatures peaked at the beginning of August at approximately 25°C (Figure 1). Maximum temperatures peaked at about 34°C. Average post-dam temperatures peaked at the beginning of August and were about 2°C warmer (Figure 2). Maximum post-dam temperatures peaked at about 32°C and occurred earlier in the summer compared to the pre-dam period. Overall, since construction of Navajo Dam, instantaneous water temperatures were warmer throughout the spring and summer at Mexican Hat (Table 1, Figure 3-Figure 5).



**Figure 1. Average, minimum and maximum instantaneous water temperatures for the San Juan River at Mexican Hat, 1945-1962 (pre-dam).**



**Figure 2. Average, minimum and maximum instantaneous water temperatures for the San Juan River at Mexican Hat, 1963-1976 (post-dam).**

**Table 1. Comparison of average, minimum and maximum instantaneous water temperatures between pre-dam and post-dam periods, San Juan River at Mexican Hat.**

		Average Instant. Temp.		Minimum Instant. Temp.		Maximum Instant. Temp.	
		Average	Range	Average	Range	Average	Range
April	Pre-Dam	12.2	9.5 - 14.2	8.0	2.8 - 11.1	16.8	12.8 - 21.7
	Post-Dam	12.9	10.8 - 15.1	9.0	5.4 - 11.0	16.9	14.4 - 19.0
May	Pre-Dam	16.0	13.0 - 17.8	11.8	9.4 - 15.0	20.0	16.7 - 22.8
	Post-Dam	17.7	15.4 - 20.2	14.0	10.5 - 18.0	21.2	18.3 - 23.3
June	Pre-Dam	19.8	16.9 - 22.0	16.0	12.8 - 20.0	23.2	20.0 - 26.1
	Post-Dam	21.3	18.7 - 23.1	17.0	13.0 - 20.6	24.9	21.0 - 29.0
July	Pre-Dam	23.9	21.9 - 25.2	20.9	18.9 - 22.8	27.9	25.0 - 33.3
	Post-Dam	25.2	23.6 - 26.6	21.9	19.0 - 24.0	28.7	26.1 - 31.7
August	Pre-Dam	22.8	21.2 - 24.5	19.4	17.2 - 21.1	26.5	23.9 - 33.9
	Post-Dam	24.2	22.3 - 26.7	20.1	16.7 - 22.0	27.8	25.0 - 30.5

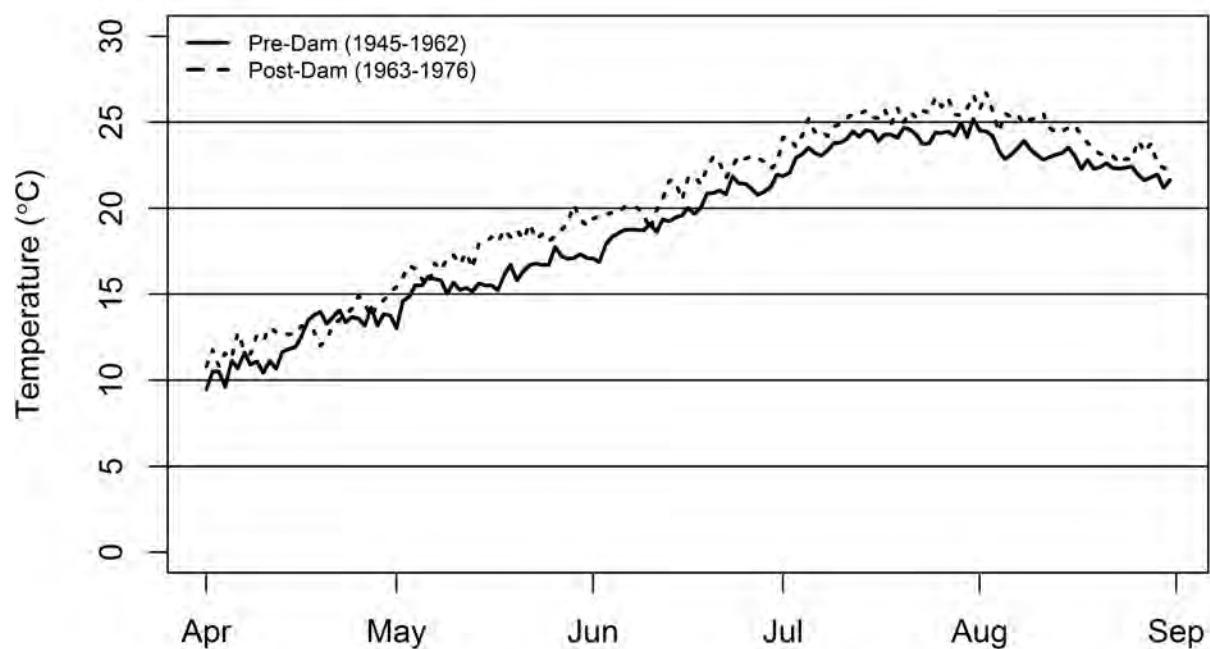


Figure 3. Pre-dam and post-dam average instantaneous temperatures, San Juan River at Mexican Hat.

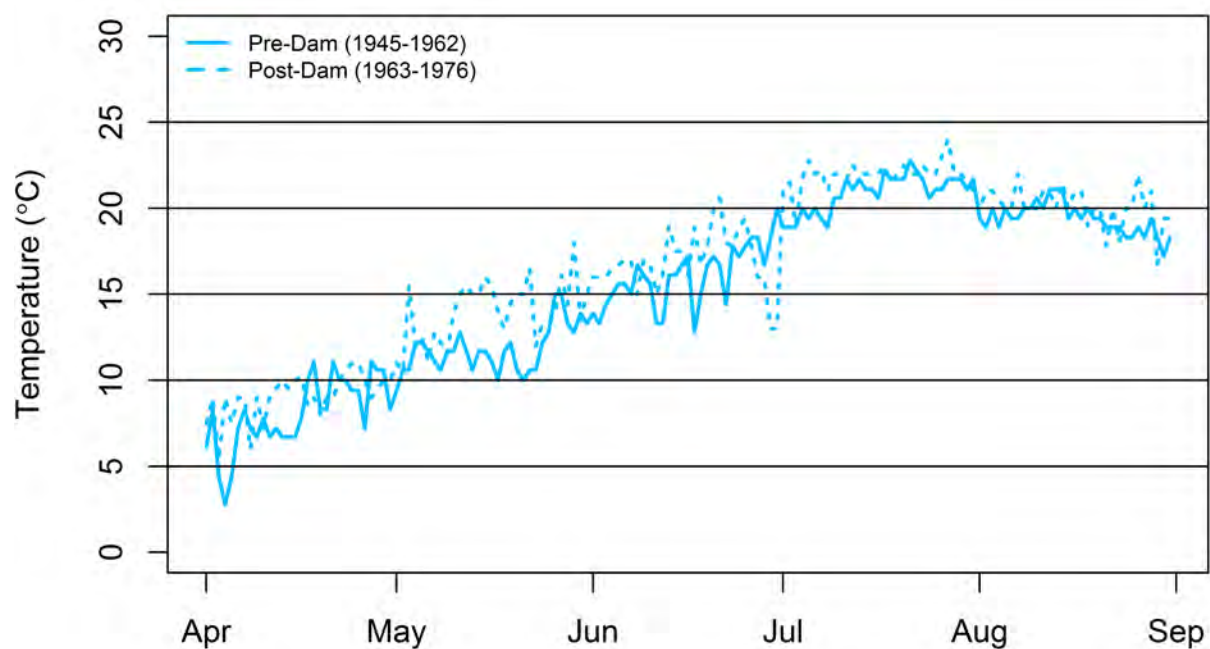
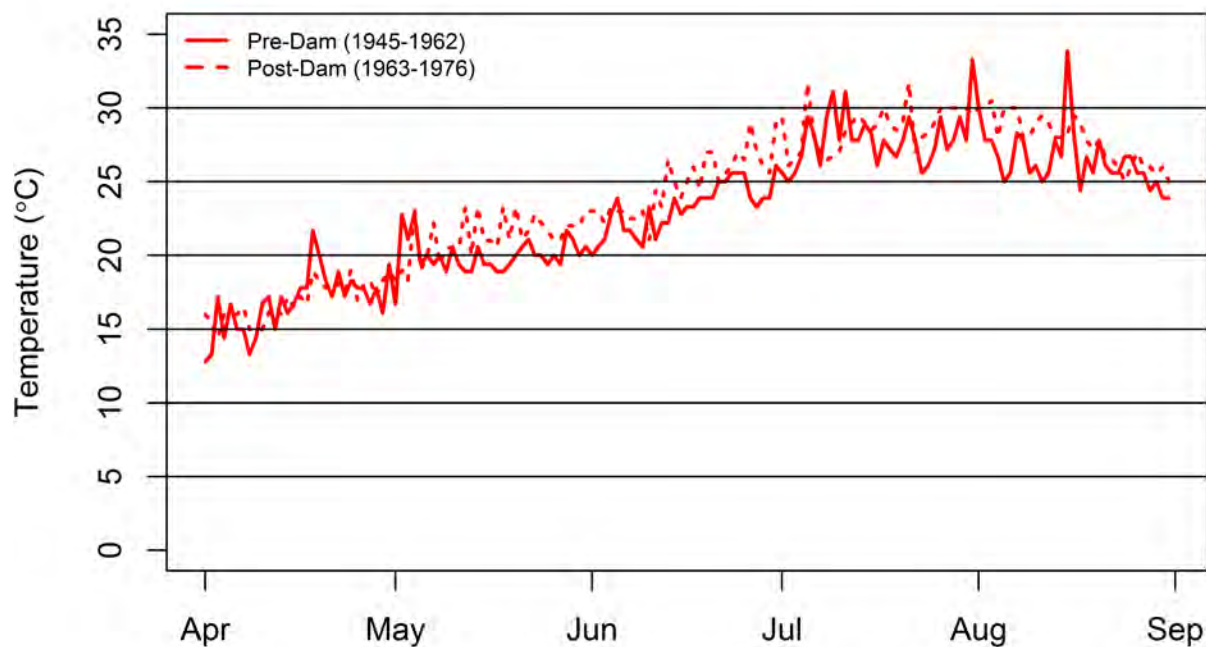


Figure 4. Pre-dam and post-dam minimum instantaneous temperatures, San Juan River at Mexican Hat.



**Figure 5. Pre-dam and post-dam maximum instantaneous temperatures, San Juan River at Mexican Hat.**

Warmer temperatures at Mexican Hat since completion of the dam are due to reduced flows. Mean pre-dam flows peaked at approximately 7500 cfs in early June (Figure 6). Maximum flows peaked at approximately 25,000 cfs and were frequently above 15,000 cfs. In contrast, for the post-dam period, mean flows peaked at less than 5000 cfs and maximum flows were almost never above 15,000 cfs (Figure 7). Figure 8-Figure 10 provide further flow comparisons between the pre-dam and post-dam periods.

### **Post-Dam Comparisons With and Without Experimental Releases**

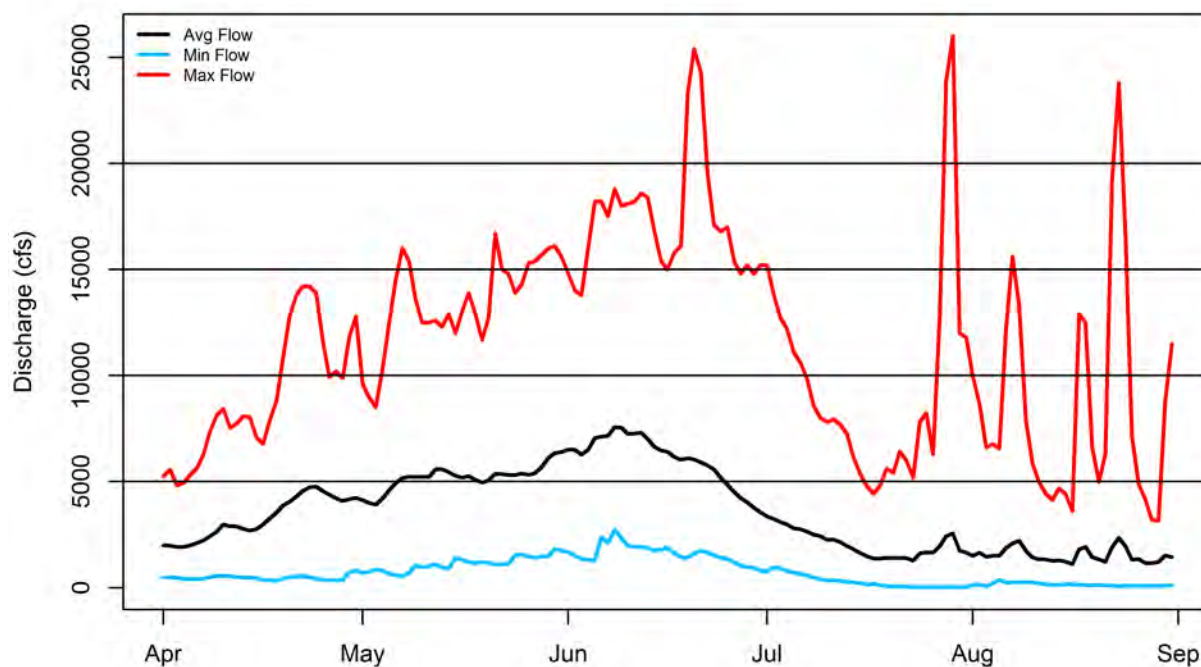
Mean average temperatures for years without releases peaked in mid-July at approximately 25°C (Figure 11). Maximum average temperatures peaked at about 31°C. Mean temperatures for years with releases also peaked in mid-July and were about 26°C, or 1°C warmer (Figure 12). Maximum average temperatures peaked at about 28°C. In general, mean average daily temperatures tend to be warmer for those years with releases compared to those without releases, with the exception of mid-May to mid-June during the time when releases are made (Figure 13). Minimum average daily temperatures also tend to be warmer for those years with releases (Figure 14), although there is more variability. Maximum average daily temperatures are even more variable between years with releases and years without (Figure 15).

Mean flows for years without releases peaked at approximately 4500 cfs in early June (Figure 16). Maximum flows peaked at approximately 12,000 cfs. For years with experimental releases,

mean flows peaked at approximately 6200 cfs and maximum flows also peaked at approximately 12,000 cfs (Figure 17). Figure 18-Figure 20 provide further monthly flow comparisons for years with and without releases.

Since the primary focus of the analysis was to evaluate the potential impacts of water temperature depression on native fish larvae, temperatures during the typical release period were assessed more thoroughly. The typical release period is from about May 15 to June 20, although release times vary from year to year and the duration of the release also varies. Mean average daily temperatures are cooler during May 15 through June 20 in years of releases (Figure 21, Table 2). On average, temperatures during years of releases are 2.1°C cooler and range from 0.2°C warmer to 3.8°C cooler.

Depending on the year, mean average daily temperature for the week preceding the release compared to the mean average daily temperature for the first week of the release for each year the temperature depression ranged from 0 to 4.8°C (Table 3). The lowest average daily temperature during a release was 6.3°C (but note that for this year, 1993, the release started in February).



**Figure 6. Mean, minimum and maximum average daily flows for the San Juan River at Mexican Hat, 1945-1962 (pre-dam).**



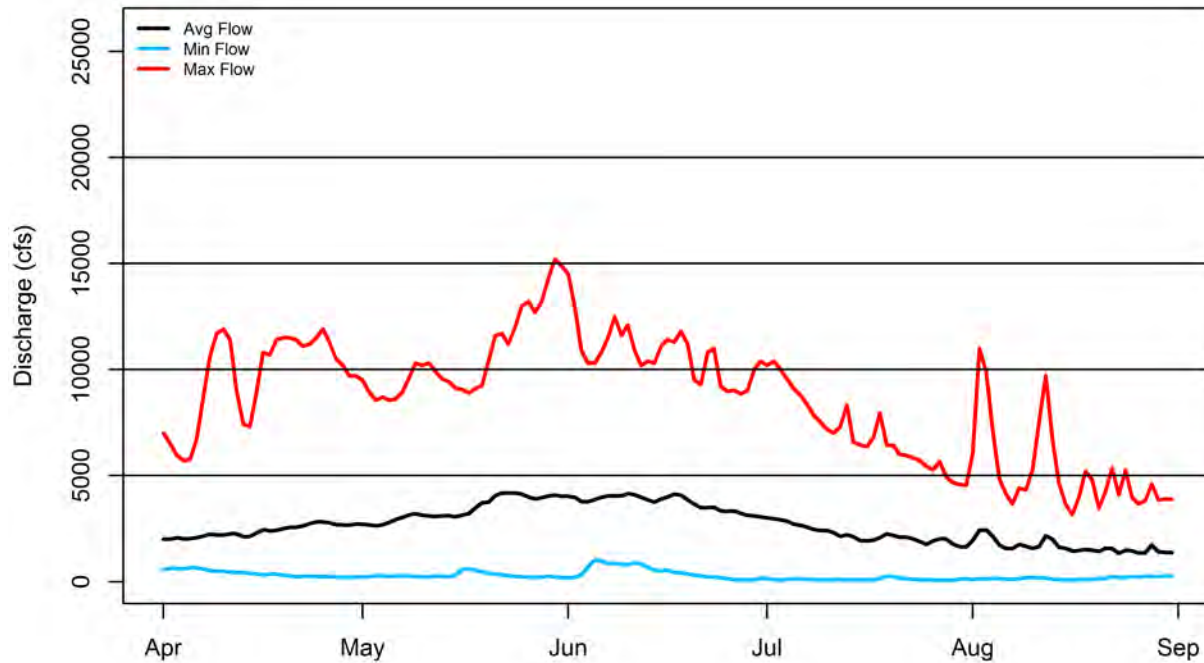


Figure 7. Mean, minimum and maximum average daily flows for the San Juan River at Mexican Hat, 1963-1976 (post-dam).

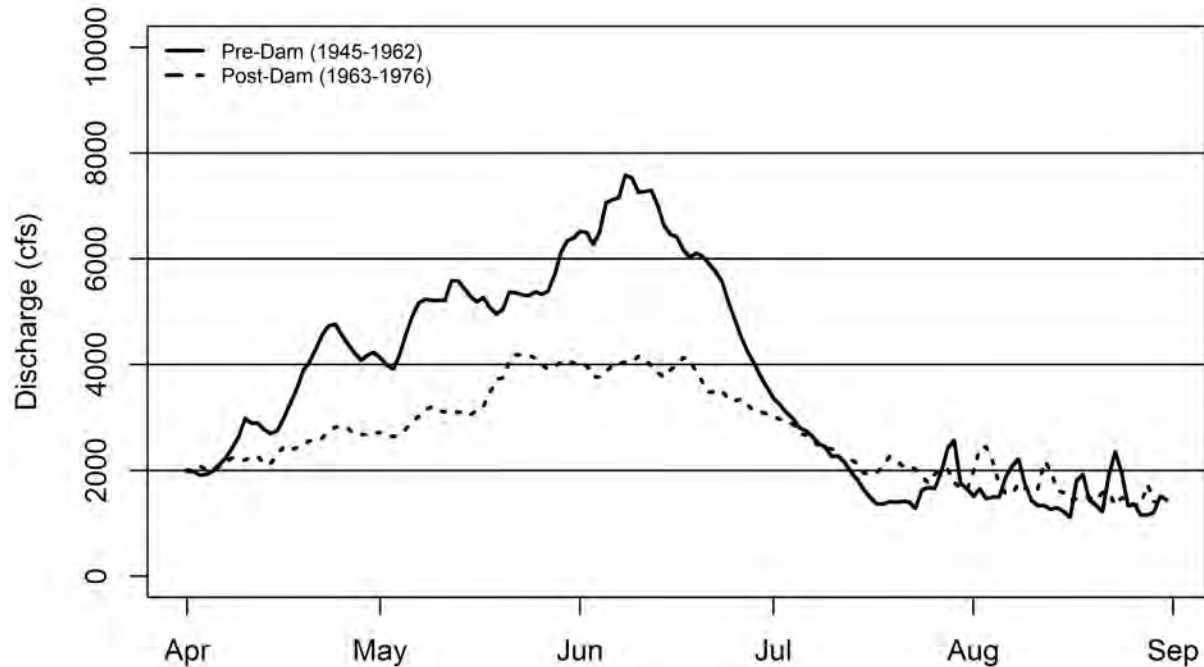


Figure 8. Pre-dam and post-dam mean average daily flows, San Juan River at Mexican Hat.

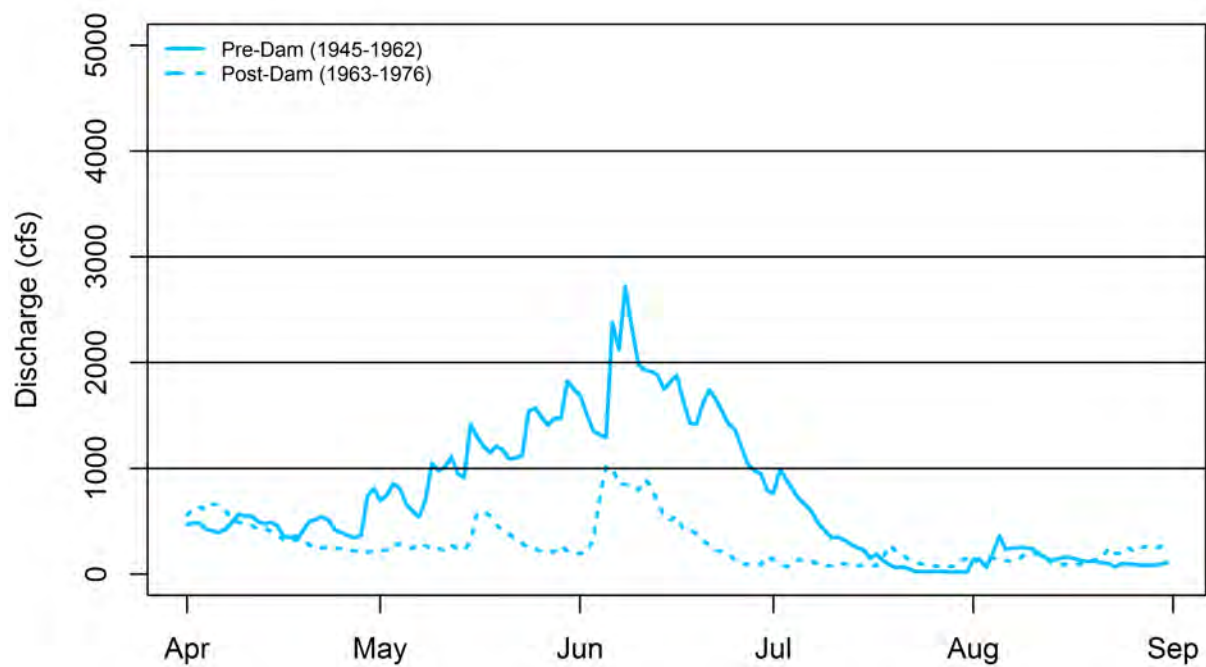


Figure 9. Pre-dam and post-dam minimum average daily flows, San Juan River at Mexican Hat.

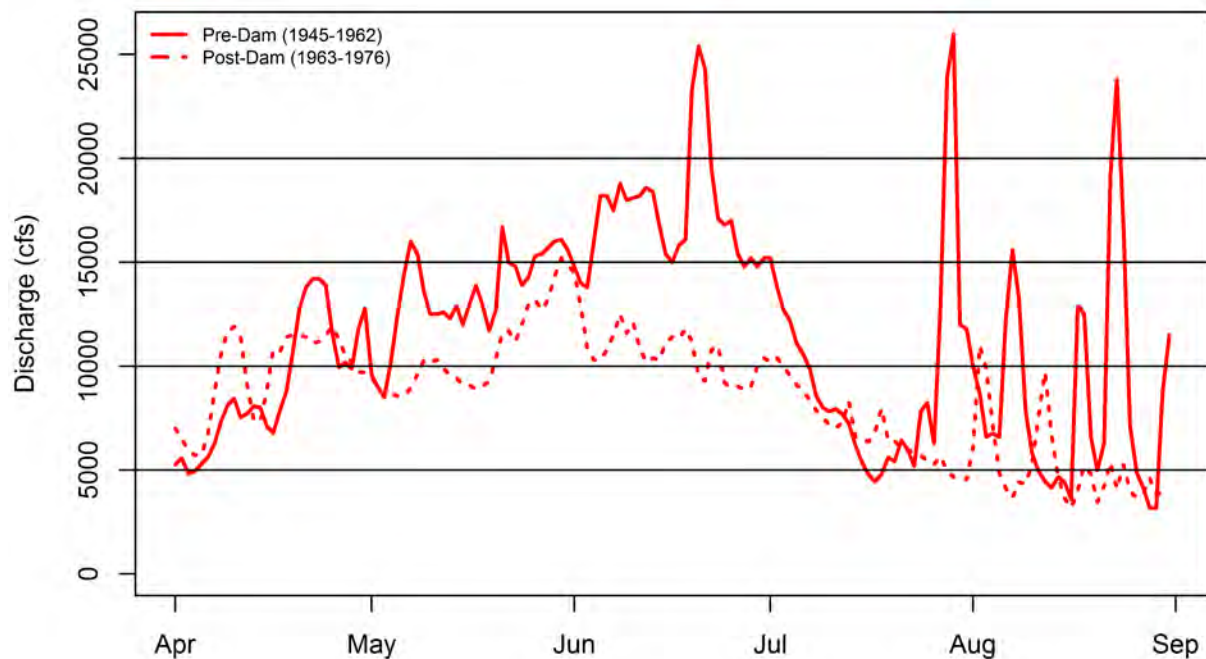


Figure 10. Pre-dam and post-dam maximum average daily flows, San Juan River at Mexican Hat.

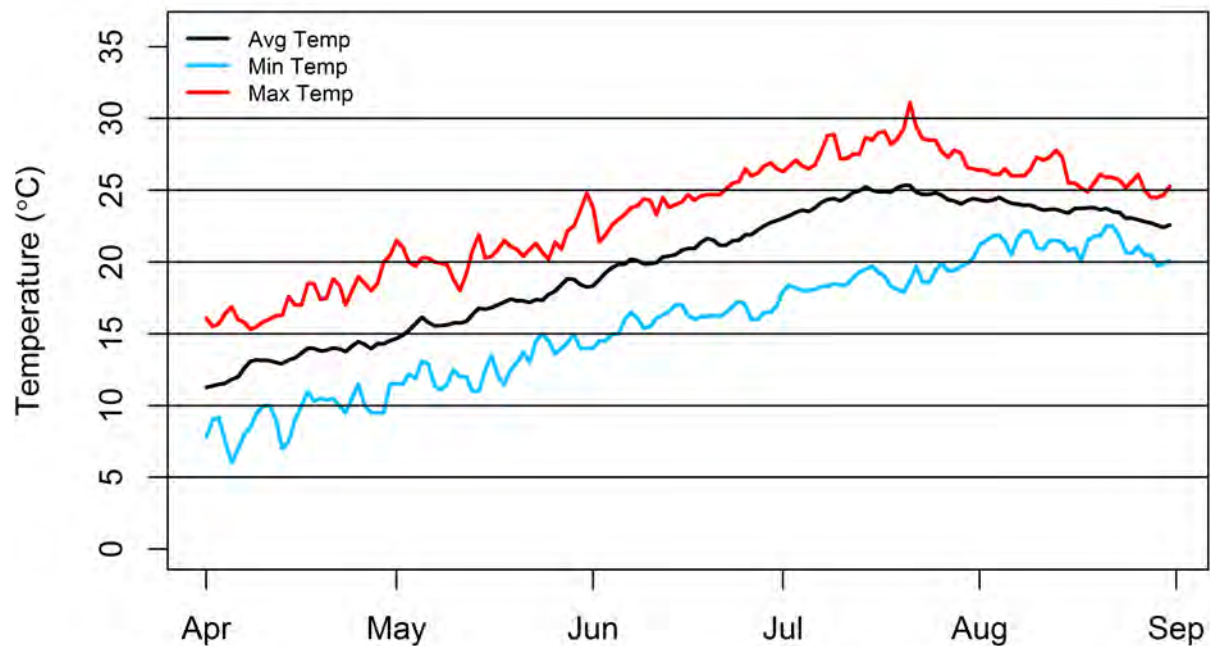


Figure 11. Mean, minimum and maximum average daily water temperatures for the San Juan River at Mexican Hat for years without experimental releases.

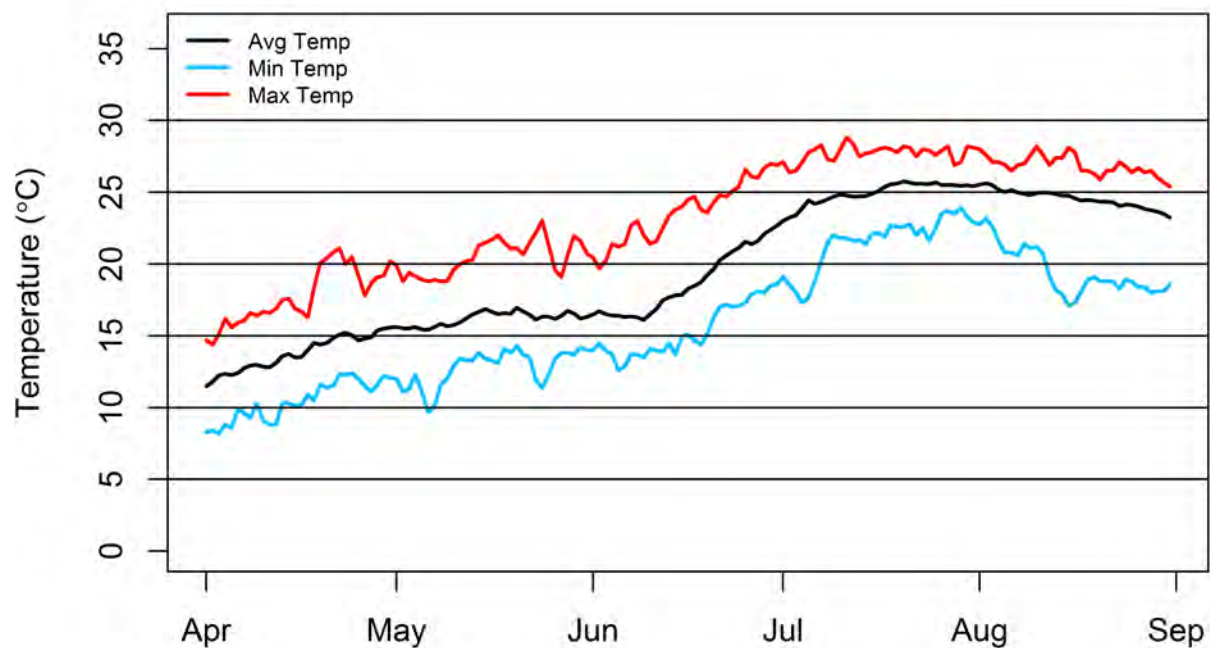


Figure 12. Mean, minimum and maximum average daily water temperatures for the San Juan River at Mexican Hat for years with experimental releases.



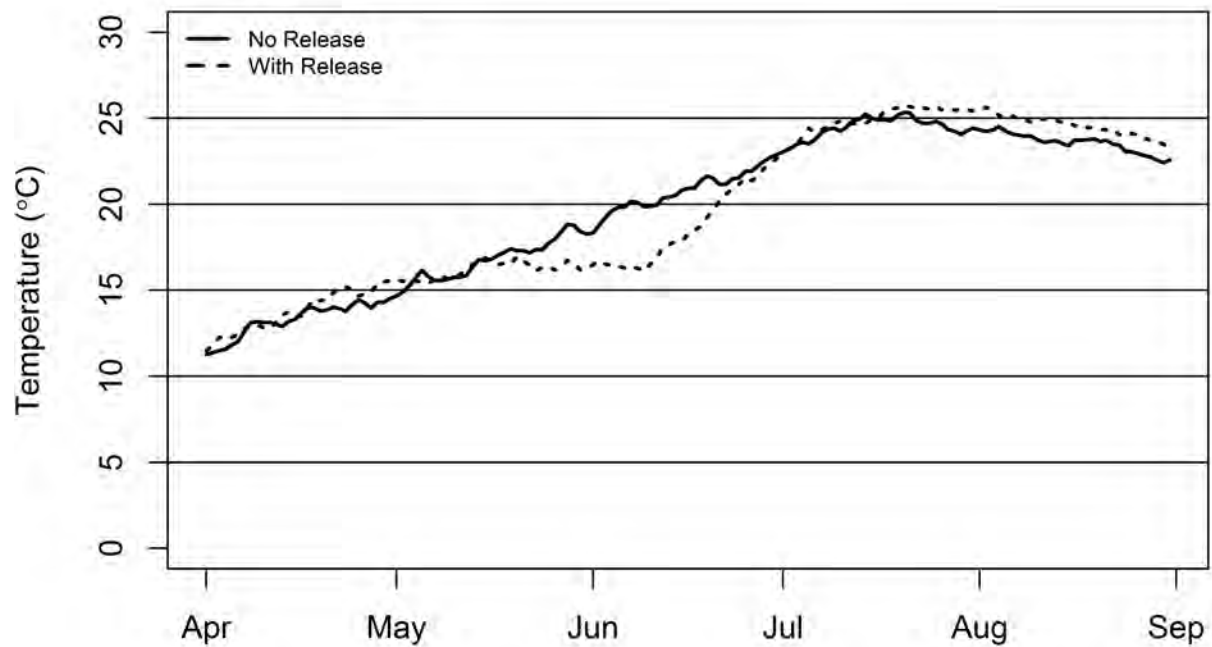


Figure 13. Mean average daily temperatures, San Juan River at Mexican Hat for years with and without experimental releases.

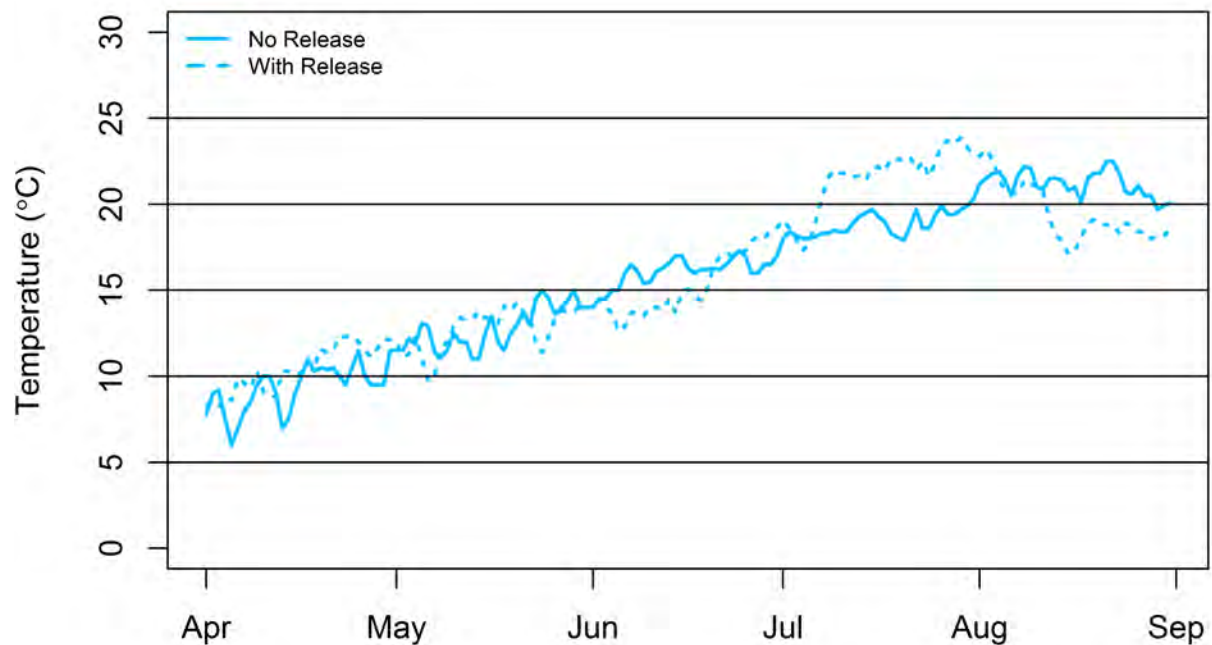


Figure 14. Minimum average daily temperatures, San Juan River at Mexican Hat for years with and without experimental releases.

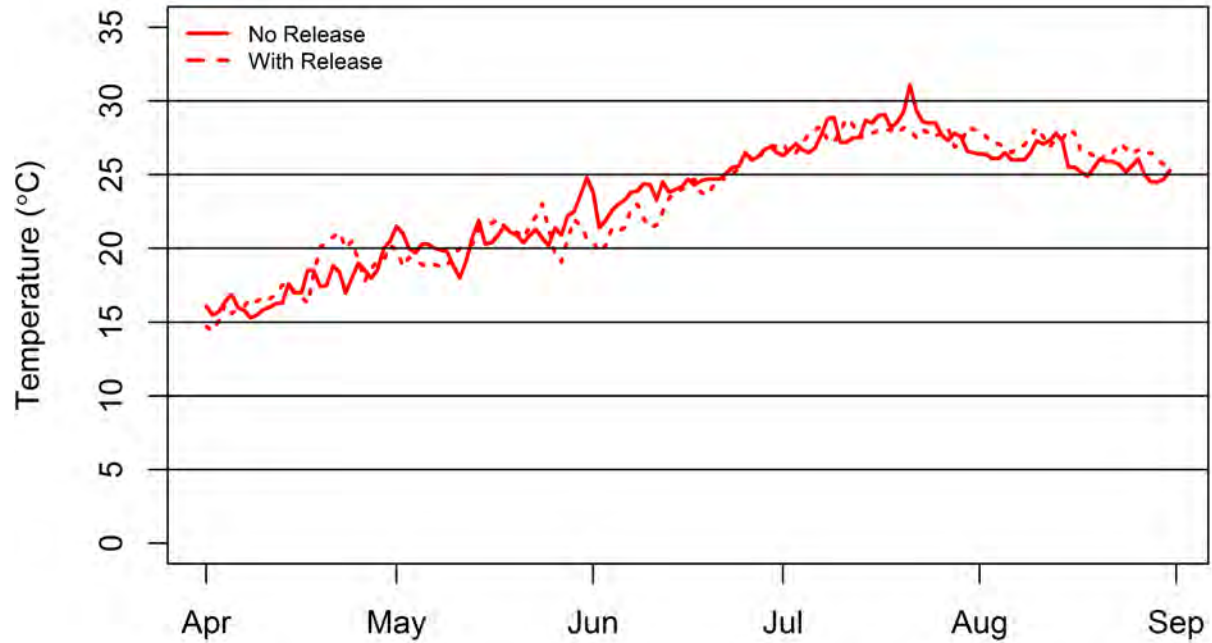


Figure 15. Maximum average daily temperatures, San Juan River at Mexican Hat for years with and without experimental releases.

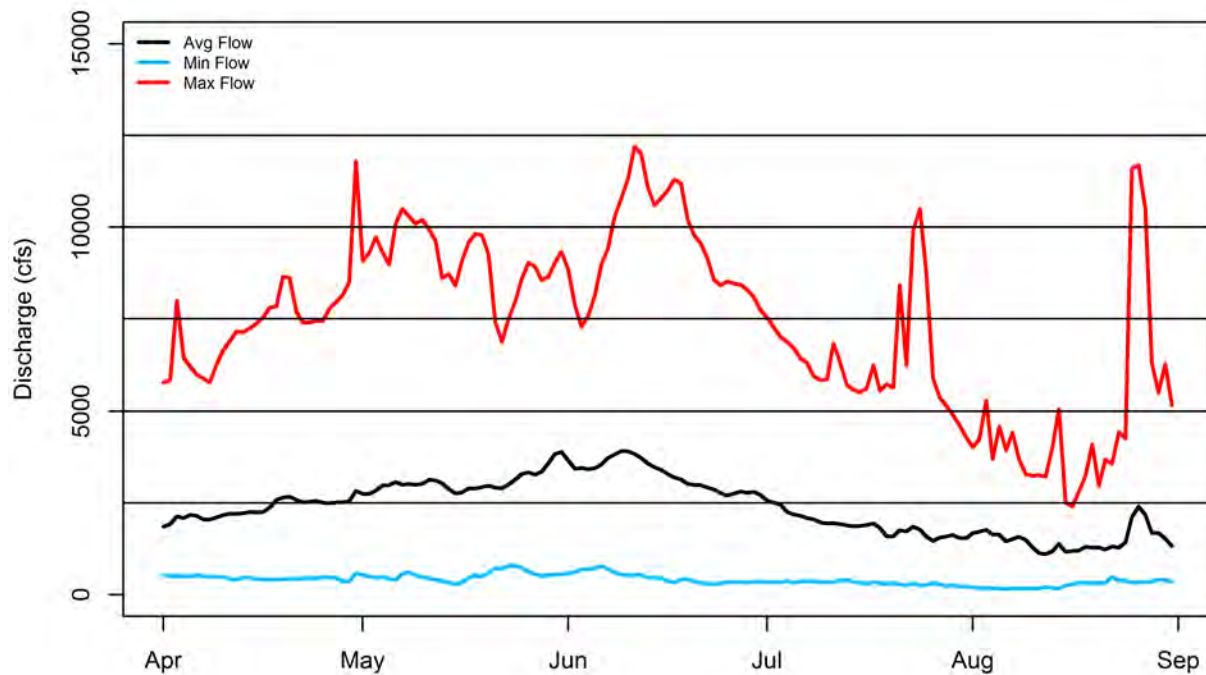


Figure 16. Mean, minimum and maximum average daily flows for the San Juan River at Mexican Hat for years without experimental releases.

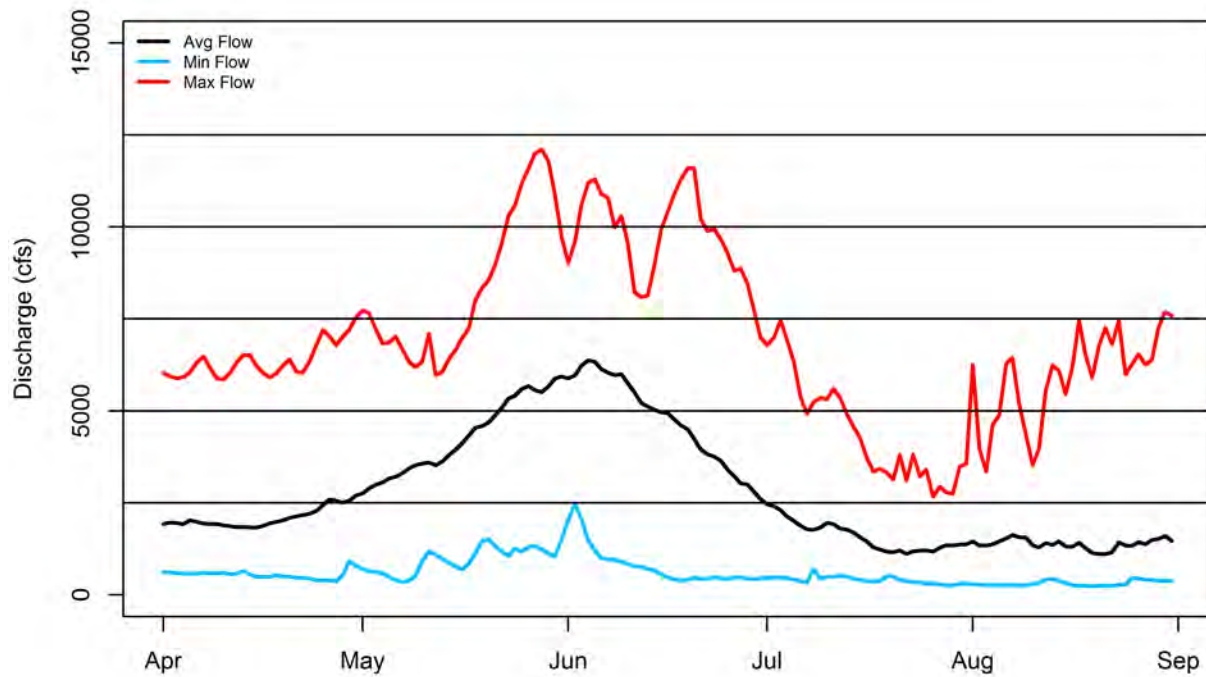


Figure 17. Mean, minimum and maximum average daily flows for the San Juan River at Mexican Hat for years with experimental releases.

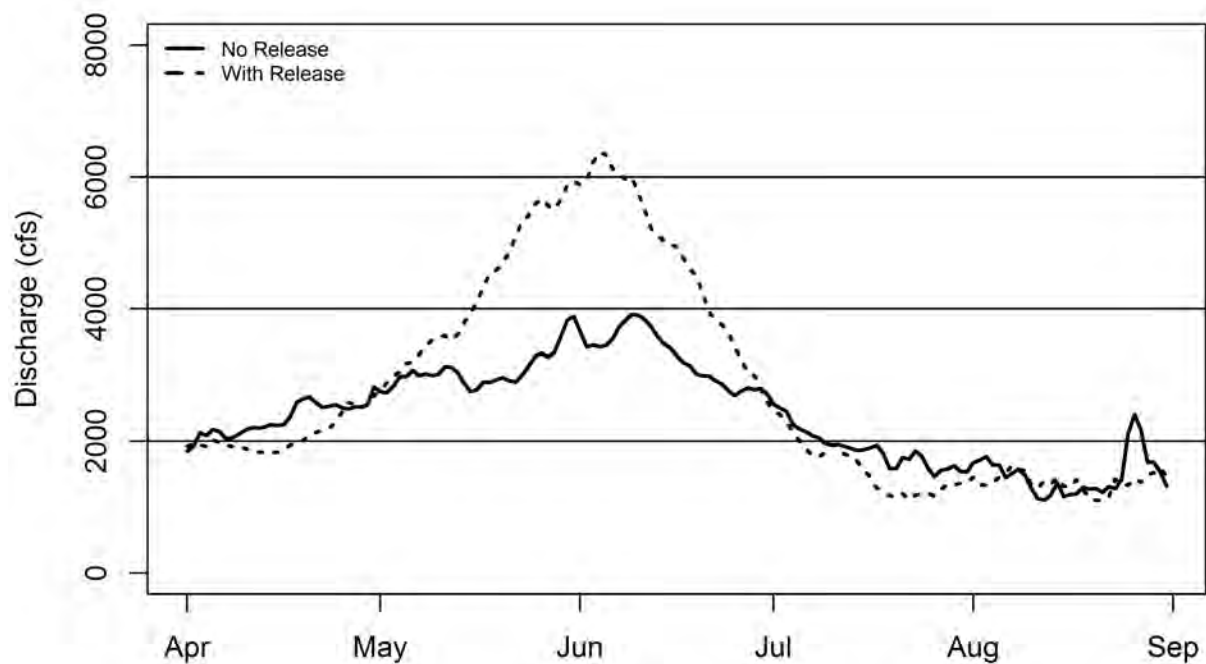


Figure 18. Mean average daily flows, San Juan River at Mexican Hat for years with and without experimental releases.

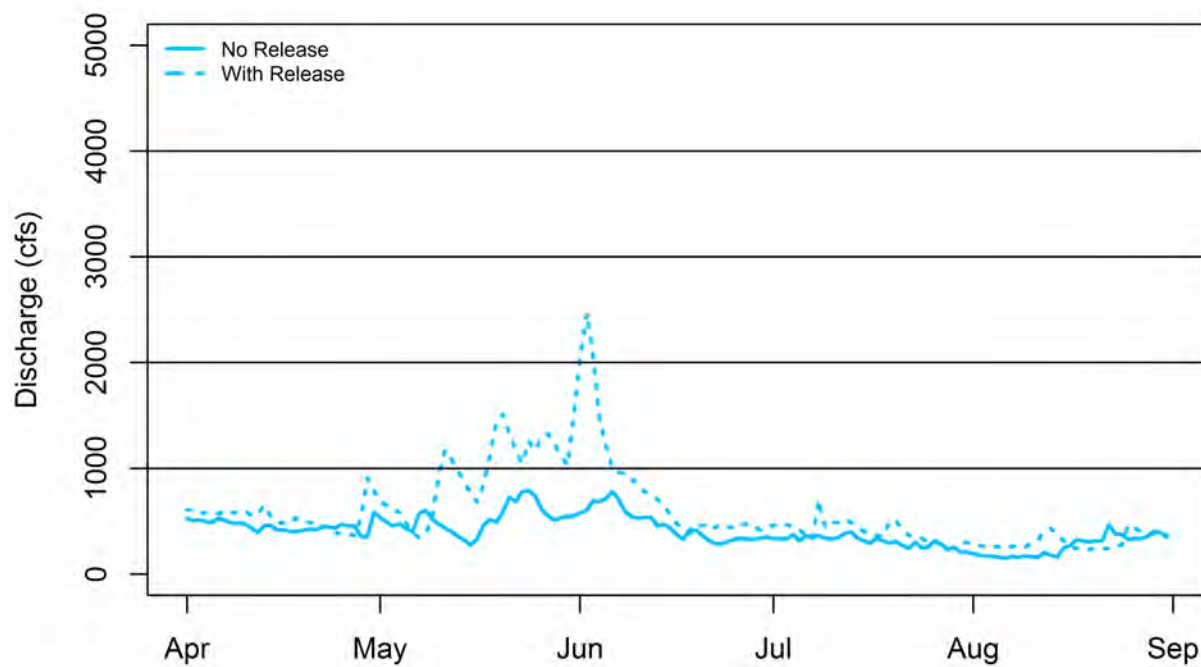


Figure 19. Minimum average daily flows, San Juan River at Mexican Hat for years with and without experimental releases.

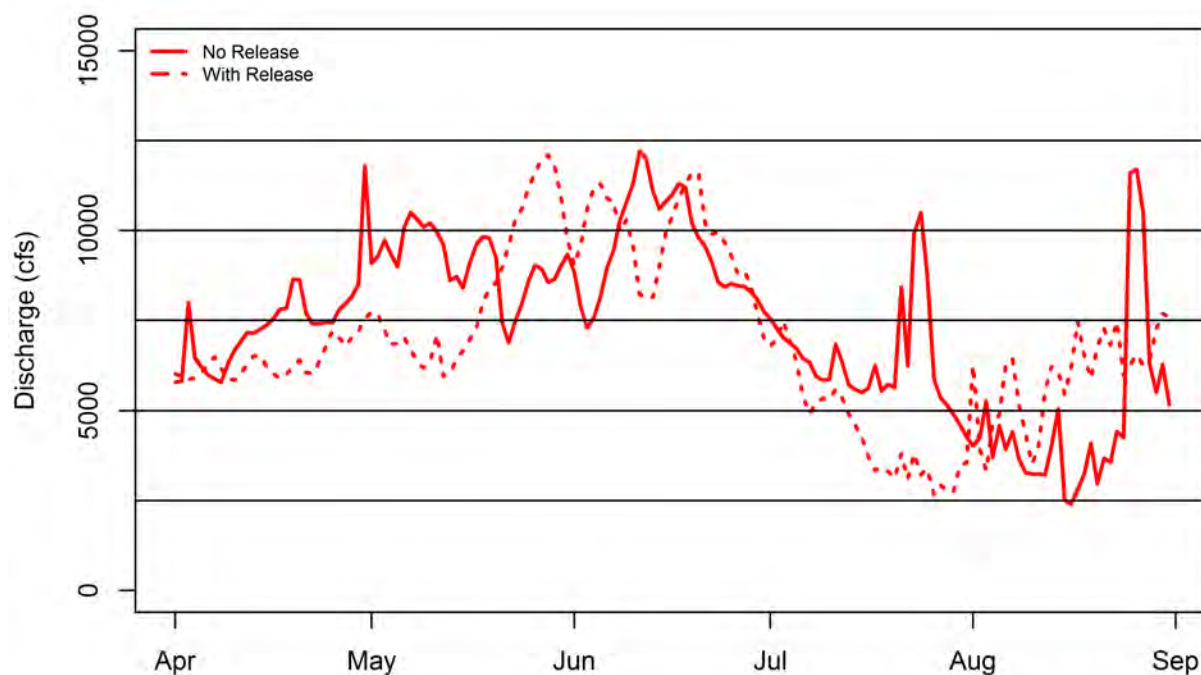


Figure 20. Maximum average daily flows, San Juan River at Mexican Hat for years with and without experimental releases.

**Table 2. Comparisons of mean average daily temperature and flow between years with experimental releases and years without releases during the typical release period, San Juan River at Mexican Hat.**

Day	Mean Average Daily Temp.			Mean Average Daily Flow		
	No Release	With Release	Difference	No Release	With Release	Difference
15-May	16.7	16.9	0.2	2754	3944	1190.5
16-May	16.8	16.7	-0.1	2783	4106	1322.8
17-May	17.0	16.5	-0.5	2895	4329	1433.8
18-May	17.2	16.6	-0.6	2892	4544	1651.8
19-May	17.4	16.5	-0.9	2929	4586	1657.3
20-May	17.3	17.0	-0.4	2963	4682	1718.5
21-May	17.3	16.7	-0.6	2916	4879	1963.2
22-May	17.2	16.5	-0.7	2898	5089	2191.1
23-May	17.4	16.1	-1.2	3004	5332	2328.1
24-May	17.4	16.3	-1.0	3136	5418	2281.7
25-May	17.7	16.3	-1.4	3285	5594	2308.4
26-May	18.0	16.2	-1.8	3333	5673	2339.7
27-May	18.4	16.4	-2.0	3272	5564	2292.1
28-May	18.8	16.7	-2.1	3347	5513	2165.9
29-May	18.8	16.6	-2.2	3582	5664	2082.0
30-May	18.4	16.2	-2.2	3827	5876	2049.8
31-May	18.3	16.3	-2.0	3886	5936	2050.9
1-Jun	18.3	16.5	-1.9	3657	5883	2225.8
2-Jun	18.8	16.7	-2.1	3427	5959	2531.7
3-Jun	19.3	16.5	-2.7	3454	6232	2778.0
4-Jun	19.6	16.4	-3.2	3422	6376	2953.4
5-Jun	19.8	16.4	-3.4	3448	6335	2887.6
6-Jun	19.9	16.3	-3.5	3541	6133	2591.6
7-Jun	20.2	16.4	-3.8	3721	6038	2316.9
8-Jun	20.1	16.3	-3.8	3820	5969	2148.8
9-Jun	19.9	16.1	-3.8	3916	5996	2080.4
10-Jun	19.9	16.5	-3.4	3903	5755	1851.6
11-Jun	20.0	16.9	-3.1	3839	5499	1660.2
12-Jun	20.4	17.5	-2.9	3723	5215	1492.0
13-Jun	20.4	17.7	-2.8	3578	5115	1536.8
14-Jun	20.5	17.8	-2.7	3475	5033	1558.7
15-Jun	20.8	17.9	-3.0	3405	4964	1559.6
16-Jun	20.9	18.3	-2.7	3292	4940	1648.2
17-Jun	20.9	18.5	-2.5	3190	4770	1579.6
18-Jun	21.4	18.7	-2.6	3144	4605	1461.4
19-Jun	21.7	19.2	-2.4	3016	4497	1481.1
20-Jun	21.5	19.6	-1.9	2994	4238	1244.0
Average	19.0	16.9	-2.1	3342	5305	1963

**Table 3. Comparisons of temperatures prior to and during experimental flow releases, San Juan River at Mexican Hat.**

Year	Mean Avg. Daily Temp. for Week Preceding Release (°C)	Mean Avg. Daily Temp. during First Week of Release (°C)	Change in Temp. (°C)	Minimum Avg. Daily Temp. during Release
1992	16.8	13.5	-3.3	11.6
1993	6.7	7.9	1.2	6.3
1994	16.4	16.1	-0.3	14.4 <sup>1</sup>
1995	No data	No data	--	No data
1996	No data	No data	--	No data
1997	17.8	15.9	-1.9	13.2 <sup>1</sup>
1998	15.9 <sup>2</sup>	15.4	-0.5	13.1
1999	No data	15.2	--	14.0 <sup>1</sup>
2000	20.5	19.2	-1.3	18.4
2001	19.1	15.8	-3.3	13.7
2005	13.2	13.6	0.4	12.1
2006	19.6	16.7	-2.9	14.9
2007	17.5	12.7	-4.8	9.7
2008	16.7	13.6	-3.1	11.4
2009	17.1	17.1	0	13.7
2011	17.7	15.4	-2.3	14.9
2012	19.8	16.0	-3.8	13.8

<sup>1</sup> Data not available for every day of the release.

<sup>2</sup> Only 5 days of data were available.

### **Comparison of Pre dam, post -dam and post-dam with release water temperature and discharge**

Further examination of water temperature and discharge shows a distinct pattern for pre-dam, post-dam and post-dam with peak releases when the daily water temperature is paired with the same day's discharge. The release from Navajo Dam is limited to a maximum of 5,000 cfs. In most years the peak discharge from the Animas River is less than 3,200 cfs, which suggests that to obtain flows greater than 5,000 cfs at Mexican Hat require a release from Navajo Dam. In addition, the threshold of 20°C is used as a reference point for Colorado Pikeminnow spawning. Marsh (1985) concluded that optimal water temperature for Colorado Pikeminnow development and hatching was 20°C.

The pre-dam comparison shows numerous days with discharge greater than 5,000 cfs and water temperature equal to or greater than 20°C (Figure 21). There are also numerous days with greater than 10,000 cfs discharge. Post-dam without a specified peak release, there are still numerous days with flows greater than 5,000 cfs and water temperatures equal to or greater than 20°C (Figure 22). Maximum discharge post-dam is limited to approximately 12,500 cfs. For the post-dam period with spring releases there are very few days when water temperature exceeds 20°C and discharge is greater than 5,000 cfs (Figure 23). For most of the days when flow is greater than 5,000 cfs the water temperature is less than 20°C.

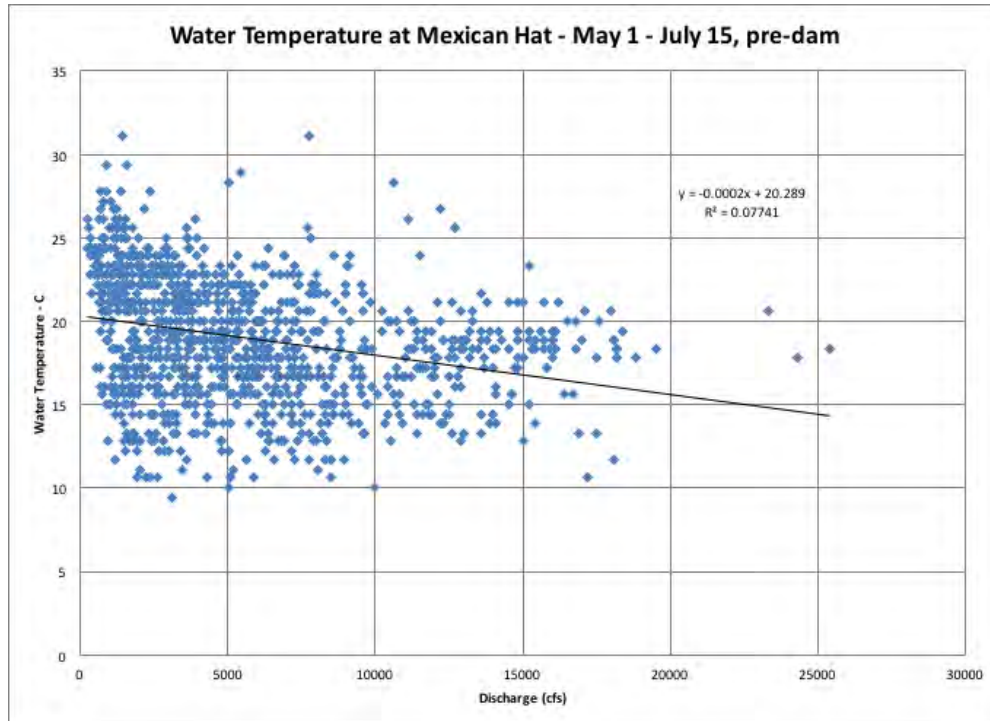


Figure 21. Comparison of San Juan River water temperature and discharge pre-dam at Mexican Hat, Utah.

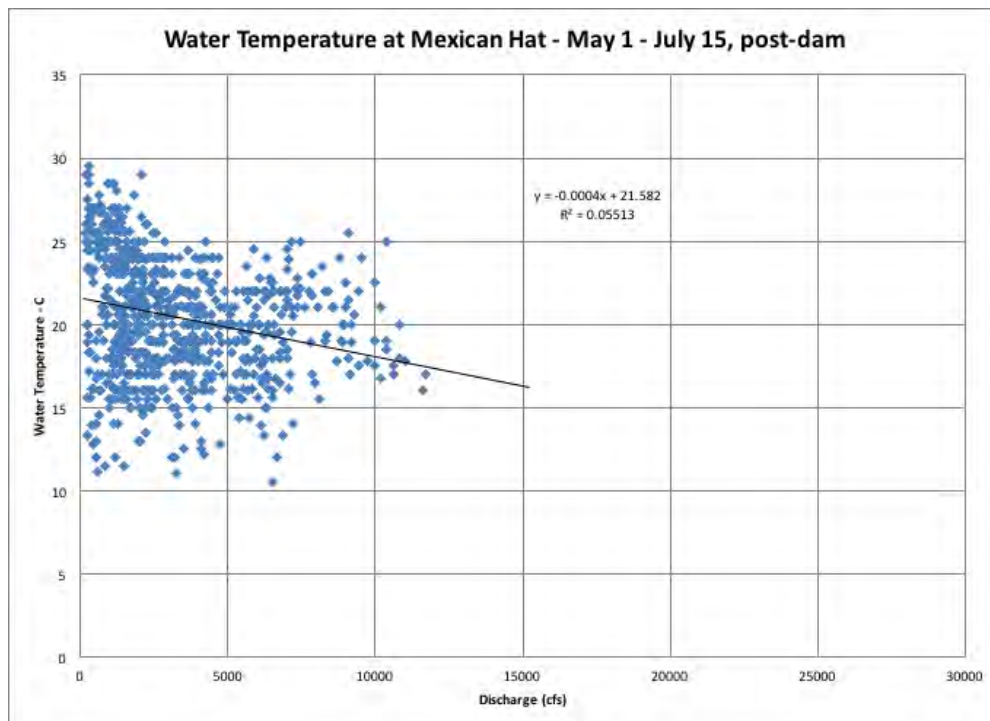
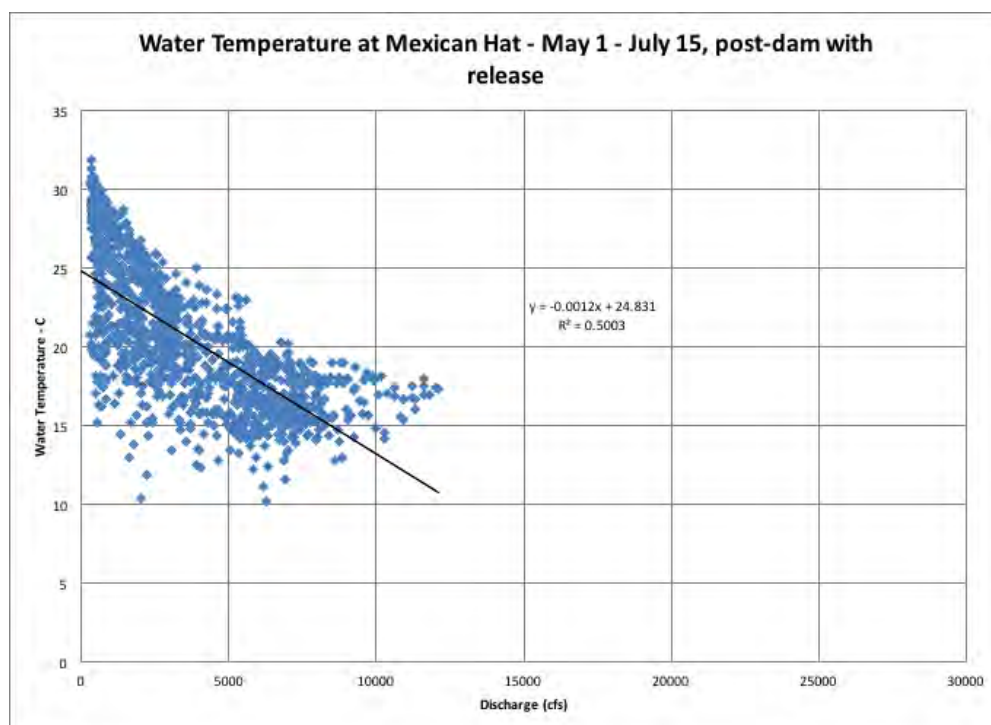


Figure 22. Comparison of San Juan River water temperature and discharge post-dam, no release, at Mexican Hat, Utah.





**Figure 23. Comparison of San Juan River water temperature and discharge post-dam and peak flows at Mexican Hat, Utah.**

### Effect of Animas River Flows

The Animas River can have a strong effect on temperatures in the San Juan River, either raising or lowering water temperatures dependent on year and relative flow differences. For years in which a large release from Navajo Dam does not occur, daily fluctuations in temperature in the San Juan River as far downstream as Mexican Hat tend to track closely with temperature fluctuations in the Animas River. For years in which a large release does occur, daily fluctuations in temperature in the San Juan River can still track with fluctuations in the Animas River if flows in the Animas River are also large. For years in which a large release occurs and flows in the Animas River are low, then the temperature depression due to the release is most apparent. The effect of Animas River flows on temperatures in the San Juan River will be discussed in greater detail in the next section.

In summary, analysis of temperature data showed that, for the San Juan River at Mexican Hat, post-dam temperatures were warmer than pre-dam temperatures throughout early spring and late summer and were the result of reduced flows. Water temperatures at Mexican Hat were cooler with releases than without releases between May 15 and June 20. Since the mid-May to mid-June period coincides with the typical release period, we conclude that the experimental releases



do have a temperature depression effect that can be detected as far downstream as Mexican Hat. Flows from the Animas River can moderate the effect of coldwater releases from Navajo Dam.

## **LARVAL FISH SURVEYS**

We compared larval fish survey data to the observed temperature regimes from each year. Larval fish surveys have been conducted since 1991. The surveys have focused on two endangered species native to the San Juan River: Colorado Pikeminnow and Razorback Sucker.

### **Drift Net Surveys – 1991-2001**

Passive drift-netting surveys occurred on the San Juan River at Mexican Hat (RM 53-55.5) and Four Corners (RM 119.2-128) from 1991-2001 (1991-1997 results summarized in Platania et al. 2000). The use of drift net data seemed advantageous since the same two locations were repetitively sampled over the spawning season, making it possible to pinpoint when larval fish were spawning and detect any patterns in spawning. However, since experimental releases began in 1992, there was only one year within this dataset in which a release did not occur. Additionally, the surveys were conducted from late June/early July through August and therefore did not occur during the typical release period. The sampling period was selected because it encompassed the reported reproductive season of Colorado Pikeminnow (Platania et al. 2000). Furthermore, no Razorback Sucker and few Colorado Pikeminnow were captured, although other native catostomids were collected. Therefore, the drift net data were of limited use for this analysis.

### **Larval Seining – 2003-2014**

The larval drift net surveys were originally designed to determine spawning period and approximate locations of spawning sites of Colorado Pikeminnow (Brandenburg 2000). However, since Razorback Sucker reproduction (March-May) occurs considerably earlier than Colorado Pikeminnow (June-July), additional surveys were deemed necessary (Brandenburg 2000). Active larval seining surveys for Razorback Sucker have been undertaken since 1998. The most complete datasets (those which provide sample effort, in order to calculate a standardized density, and distinguish between age-0 and age-1 fish) began in 2003. Few Colorado Pikeminnow have been captured during the larval surveys since 2003 with the exception of 2014 (Table 4). Therefore, our analysis focused on Razorback Sucker and other native catostomids because these species have been collected in greater numbers.

**Table 4. Total counts of age-0 Colorado Pikeminnow and Razorback Sucker and density of Razorback Sucker collected during larval fish surveys.**

Year	# of Age-0 Colorado Pikeminnow	# of Age-0 Razorback Sucker	Density (number/m <sup>2</sup> ) of Age-0 Razorback Sucker
2003	0	463	0.035
2004	2	41	0.003
2005	0	19	0.002
2006	0	202	0.016
2007	3	200	0.015
2008	0	126	0.009
2009	1	272	0.017
2010	5	1,251	0.075
2011	29	1,065	0.113
2012	0	1,778	0.215
2013	12	826	0.100
2014	312	612	0.071

The following subsections summarize the yearly seining survey results for Razorback Sucker and two other native catostomids, Bluehead Sucker *Catostomus discobolus* and Flannemouth Sucker *Catostomus latipinnis*. Bluehead Sucker and Flannemouth Sucker were assessed because both species generally spawn at the same time as Razorback Sucker. Differences in patterns of abundance may help elucidate why the Razorback Sucker population is low while Bluehead Sucker and Flannemouth Sucker are abundant. Average daily temperature data from the San Juan River at Archuleta (the location nearest Navajo Dam) and Mexican Hat and the Animas River at its confluence with the San Juan River are also included to illustrate the extent to which water temperature changes from downstream of Navajo Dam and how the Animas River affects temperatures in the San Juan River. Figures that accompany the discussion are provided in Appendix A.

#### Year with experimental releases

No experimental releases were made in 2003, 2004, and 2010. In 2003, Razorback Sucker (n=463) were captured in May and June only, whereas Bluehead Sucker (n=1,318) were captured from May through September and Flannemouth Sucker (n=5,047) were captured from April through September (Figure A-1 and Figure A-2). Razorback Sucker were not captured as far upstream as the other two sucker species. For all three species, the captures in May

corresponded to the ascending limb of the hydrograph. Peak runoff at Mexican Hat was from May 16 to June 15 and was due to Animas River flows (Figure A-3). Mean average daily temperature during the runoff for the San Juan River at Archuleta was 9.6°C (7.5 – 10.2°C) (Figure A-4). Mean average daily temperature for the Animas River was 13.9°C (11.5 – 17.9°C). Finally, mean average daily temperature for the San Juan River at Mexican Hat was 20.9°C (19.3 – 23.9°C).

In 2004, Razorback Sucker numbers were low (n=41) and were captured in May and June only, whereas Bluehead Sucker (n=6,387) were captured from May through September and Flannemouth Sucker (n=3,145) were captured from April through July and September (Figure A-5 and Figure A-6). Peak runoff at Mexican Hat was from May 6 to June 13 and was due to Animas River flows (Figure A-7). Mean average daily temperature during the runoff for the San Juan River at Archuleta was 10.1°C (8.1 – 11.9°C) (Figure A-8). Mean average daily temperature for the Animas River was 12.3°C (9.1 – 14.9°C). Finally, mean average daily temperature for the San Juan River at Mexican Hat was 18.9°C (15.6 – 22.9°C). Daily fluctuations in temperature at Mexican Hat tracked closely with temperature fluctuations in the Animas River.

In 2010, Razorback Sucker (n=1,251) were captured from May through July. Bluehead Sucker (n=2,416) were captured from May through September and Flannemouth Sucker (n=5,453) were captured from May through September (Figure A-29 and Figure A-30). Peak runoff at Mexican Hat was from May 20 to June 16 and was due to Animas River flows (Figure A-31). Back-calculated hatching dates indicated that Razorback Sucker hatched from April 28 to June 11, or prior to peak runoff and through the runoff period (Brandenburg and Farrington 2011). Mean average daily temperature during the runoff for the San Juan River at Archuleta was 9.4°C (8.5 – 10.5°C) (Figure A-32). Mean average daily temperature for the Animas River was 13.2°C (10.8 – 15.3°C). Finally, mean average daily temperature for the San Juan River at Mexican Hat was 19.2°C (15.4 – 22.9°C). Daily fluctuations in temperature at Mexican Hat tracked closely with temperature fluctuations in the Animas River.

In 2013, Razorback Sucker (n=826) were captured from May through July. Bluehead Sucker (n=6,560) were captured from May through August and Flannemouth Sucker (n=1,697) were captured from April through August (Figure A-41 and Figure A-42). Peak runoff at Mexican Hat was from April 27 to June 1 and was due to Animas River flows (Figure A-43). Back-calculated hatching dates indicated that Razorback Sucker hatched from April 10 to June 7, or prior to peak runoff and through the runoff period (Farrington et al. 2014). Mean average daily temperature during the runoff for the San Juan River at Archuleta was 10.1°C (7.4 – 11.9°C) (Figure A-44). Mean average daily temperature for the Animas River was 13.3°C (10.7 – 17.3°C). Finally, mean average daily temperature for the San Juan River at Mexican Hat was

18.1°C (14.6 – 21.9°C). Daily fluctuations in temperature at Mexican Hat tracked closely with temperature fluctuations in the Animas River.

In 2014, Razorback Sucker (n=612) were captured from April through July. Bluehead Sucker (n=3,024) were captured from April through July and Flannelmouth Sucker (n=1,945) were captured from April through July (Figure A-45 and Figure A-46). Peak runoff at Mexican Hat was from May 21 to June 24 and was due to Animas River flows (Figure A-47). Back-calculated hatching dates for Razorback Sucker are not yet available. Mean average daily temperature during the runoff for the San Juan River at Archuleta was 11.1°C (8.7 – 11.9°C) (Figure A-48). Mean average daily temperature for the Animas River was 13.0°C (10.0 – 16.9°C). Finally, mean average daily temperature for the San Juan River at Mexican Hat was 19.2°C (15.8 – 23.0°C). Daily fluctuations in temperature at Mexican Hat tracked closely with temperature fluctuations in the Animas River.

#### Years with experimental releases

Experimental releases were made in 2005, 2006, 2007, 2008, 2009, 2011, and 2012. In 2005, Razorback Sucker numbers were low (n=19) but were captured from May through August. Bluehead Sucker (n=7,343) were captured from May through September and Flannelmouth Sucker (n=3,020) were captured from April through September (Figure A-9 and Figure A-10). Peak runoff at Mexican Hat was from May 6 to June 22 and the Animas River provided a large percentage of the flow (Figure A-11). Back-calculated hatching dates indicated that Razorback Sucker hatched from April 26 to July 2, or prior to peak runoff and through the runoff period (Brandenburg and Farrington 2006). Mean average daily temperature during the runoff for the San Juan River at Archuleta was 6.7°C (5.9 – 8.8°C) (Figure A-12). Mean average daily temperature for the Animas River was 11.5°C (9.3 – 15.2°C). Finally, mean average daily temperature for the San Juan River at Mexican Hat was 15.4°C (13.3 – 19.2°C). Daily fluctuations in temperature at Mexican Hat tracked closely with temperature fluctuations in the Animas River. Overall, there was little temperature depression at Mexican Hat even though a release occurred because a large portion of the flow came from the Animas River.

In 2006, Razorback Sucker (n=202) were captured in April and May. Bluehead Sucker (n=4,059) were captured from May through August and Flannelmouth Sucker (n=5,369) were captured from April through September (Figure A-13 and Figure A-14). Peak runoff at Mexican Hat was from May 16 to June 17. The Animas River provided a large percentage of the flow for the first ten days of the runoff and then a majority of the flow was due to the release (Figure A-15). Back-calculated hatching dates indicated that Razorback Sucker hatched from April 11 to May 24, or prior to peak runoff and before runoff peaked (Brandenburg and Farrington 2007). Mean average daily temperature during the runoff for the San Juan River at Archuleta was 7.5°C (5.8 – 10.4°C) (Figure A-16). Mean average daily temperature for the Animas River was 14.1°C

(10.8 – 17.5°C). Finally, mean average daily temperature for the San Juan River at Mexican Hat was 18.4°C (14.9 – 22.0°C). Daily fluctuations in temperature at Mexican Hat did not track closely with temperature fluctuations in the Animas River during the runoff period and flows from the release served to depress temperatures at Mexican Hat.

In 2007, Razorback Sucker (n=200) were captured from April to July, but primarily in May and June. Bluehead Sucker (n=7,996) were captured from April through August and Flannemouth Sucker (n=16,539) were captured from April through September (Figure A-17 and Figure A-18). Peak runoff at Mexican Hat was from May 2 to May 29, the majority of which was due to the release (Figure A-19). Back-calculated hatching dates indicated that Razorback Sucker hatched from March 26 to June 17, or prior to peak runoff and through the runoff period (Brandenburg and Farrington 2008). Mean average daily temperature during the runoff for the San Juan River at Archuleta was 6.0°C (5.0 – 7.2°C) (Figure A-20). Mean average daily temperature for the Animas River was 11.9°C (8.1 – 14.7°C). Finally, mean average daily temperature for the San Juan River at Mexican Hat was 14.7°C (9.7 – 19.5°C). Daily fluctuations in temperature at Mexican Hat somewhat tracked with temperature fluctuations in the Animas River during the runoff period, but there was still a considerable temperature depression, due to the release.

In 2008, Razorback Sucker (n=126) were captured in May and June. Bluehead Sucker (n=1,390) were captured from May through September and Flannemouth Sucker (n=20,259) were captured from May through September (Figure A-21 and Figure A-22). Peak runoff at Mexican Hat was from May 19 to June 26, with roughly equal percentages of flow coming from the release and from the Animas River (Figure A-23). Back-calculated hatching dates indicated that Razorback Sucker hatched from April 30 to June 13, or prior to peak runoff and through the runoff period (Brandenburg and Farrington 2009). Mean average daily temperature during the runoff for the San Juan River at Archuleta was 6.0°C (5.0 – 7.2°C) (Figure A-24). Mean average daily temperature for the Animas River was 11.9°C (8.1 – 14.7°C). Finally, mean average daily temperature for the San Juan River at Mexican Hat was 14.7°C (9.7 – 19.5°C). Daily fluctuations in temperature at Mexican Hat tracked with temperature fluctuations in the Animas River during the runoff period. The temperature depression seen in the early part of the runoff was primarily due to flows from the Animas River, not the release.

In 2009, Razorback Sucker (n=272) were captured in May and June. Bluehead Sucker (n=1,012) were captured from May through September and Flannemouth Sucker (n=3,349) were captured from May through September (Figure A-25 and Figure A-26). Peak runoff at Mexican Hat was from April 24 to June 15. The Animas River provided most of the flow until May 27; then most of the flow came from the release (Figure A-27). Back-calculated hatching dates indicated that Razorback Sucker hatched from April 12 to June 10, or prior to peak runoff and through the runoff period (Brandenburg and Farrington 2010). Mean average daily temperature during the runoff for the San Juan River at Archuleta was 8.2°C (6.4 – 10.1°C) (Figure A-28). Mean average daily temperature for the Animas River was 12.2°C (8.8 – 16.5°C). Finally, mean

average daily temperature for the San Juan River at Mexican Hat was 16.4°C (13.7 – 19.3°C). Daily fluctuations in temperature at Mexican Hat tracked with temperature fluctuations in the Animas River during the runoff period until May 27, when the release from Navajo Dam occurred. The temperature depression is apparent at Mexican Hat from May 27 until the release ends.

In 2011, Razorback Sucker (n=1,065) were captured from May through July (but primarily May and June). Bluehead Sucker (n=4,503) were captured from May through August and Flannelmouth Sucker (n=5,849) were captured from April through August (as of 2011, sampling was no longer conducted in September) (Figure A-33 and Figure A-34). Peak runoff at Mexican Hat was from May 30 to June 23. The Animas River provided most of the flow for the first week and then flows were approximately equal from the Animas River and the release (Figure A-35). Back-calculated hatching dates indicated that Razorback Sucker hatched from April 10 to June 5, or prior to peak runoff and into the peak flows (Brandenburg et al. 2012). Mean average daily temperature during the runoff for the San Juan River at Archuleta was 8.3°C (6.6 – 10.4°C) (Figure A-36). Mean average daily temperature for the Animas River was 11.9°C (10.7 – 14.0°C). Finally, mean average daily temperature for the San Juan River at Mexican Hat was 17.0°C (14.9 – 21.6°C). Daily fluctuations in temperature at Mexican Hat tracked with temperature fluctuations in the Animas River during the runoff period. The temperature depression is due both to the release and to flows from the Animas River.

In 2012, Razorback Sucker (n=1,778) were captured in May and June. Bluehead Sucker (n=7,944) were captured from May through August and Flannelmouth Sucker (n=7,162) were captured from April through August (Figure A-37 and Figure A-38). Peak runoff at Mexican Hat was from May 23 to June 3 and was due to the release (Figure A-39). Back-calculated hatching dates indicated that Razorback Sucker hatched from April 5 to June 5, or prior to peak runoff and through the runoff period (Farrington et al. 2013). Mean average daily temperature during the runoff for the San Juan River at Archuleta was 6.5°C (6.0 – 7.9°C) (Figure A-40). Mean average daily temperature for the Animas River was 15.4°C (13.6 – 17.5°C). Finally, mean average daily temperature for the San Juan River at Mexican Hat was 16.5°C (13.8 – 20.4°C). 2012 provided the clearest example of the temperature depression that can occur as a result of releases from Navajo Dam. Tied to the depression was the lack of a peak runoff period for the Animas River.

A simple comparison Razorback sucker density and years with and without water temperature depression shows a difference in density for years prior to 2010 and after 2010. There is similar density for 1999 through 2001 and 2004 through 2009 (Table 5). There is a similar density for years 2011 through 2014. There are both years with and without water temperature depressions across those two different densities. While there are density differences by year, it does not appear to be caused by water temperature depressions.

**Table 5. Comparison of Razorback Sucker density with and without a water temperature depression at Mexican Hat.**

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Temperature Depression																
No Temperature Depression																
Density A																
Density B																

### ANOVA Results

The temperature data from 2003 to 2014 demonstrate that the Animas River moderates the effects of coldwater releases from Navajo Dam. When flows from the Animas River are high and contribute to a large percentage of the flow in the San Juan River, temperature fluctuations at Mexican Hat tend to track closely with those in the Animas River.

ANOVA results indicated that temperatures at Mexican Hat during the runoff period were significantly warmer for years without releases (mean = 19.3°C) compared to years with releases, regardless of the extent of temperature depression (means = 16.5°C and 16.0°C) (Figure 24). The same results were found for temperatures at Archuleta (Figure 25), where the mean temperature for years without releases was 10.1°C, compared to 7.1°C and 7.3°C for years with releases. Logically, there were no significant differences in temperature for the Animas River between the categories (Figure 26). In terms of fish density, there were no significant differences in density between the three categories for any of the native suckers (Figure 27 - Figure 29).

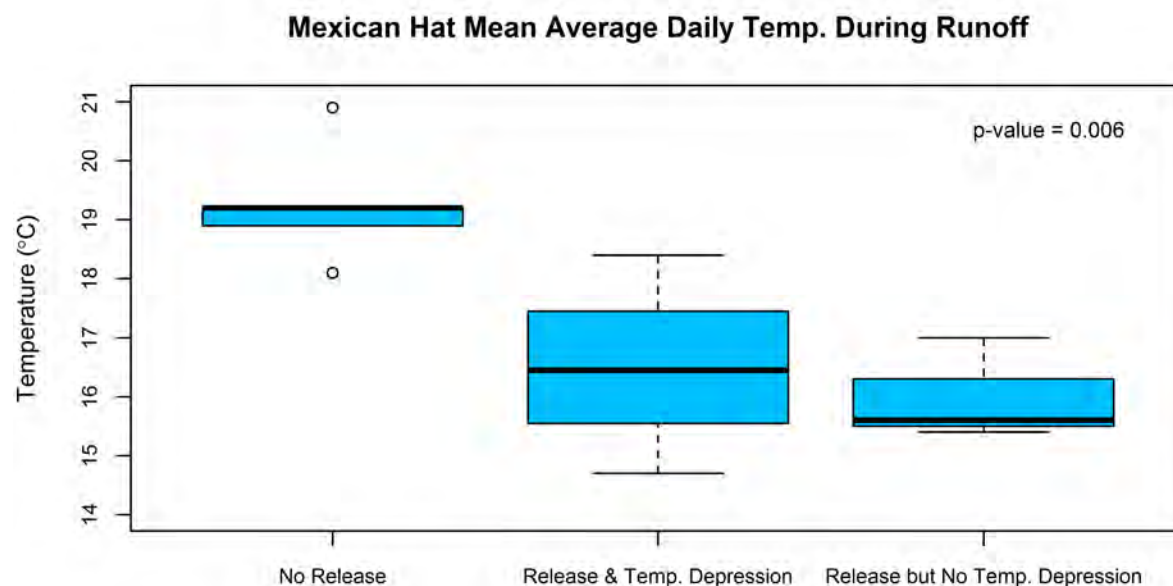


Figure 24. Comparison of mean average daily temperature during the runoff period at Mexican Hat. Open circles indicate data outliers.

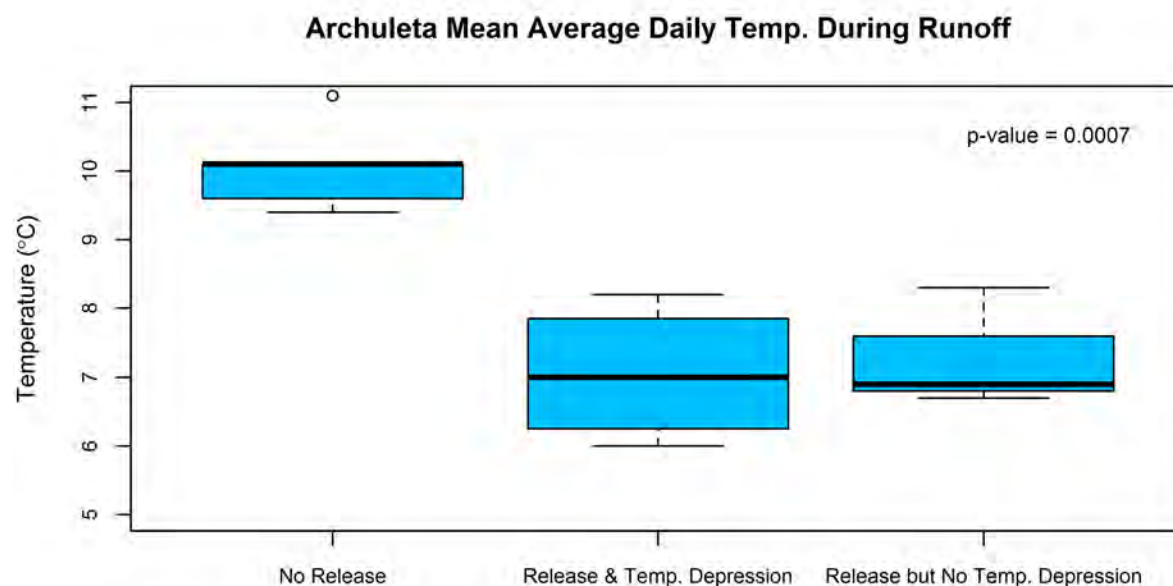
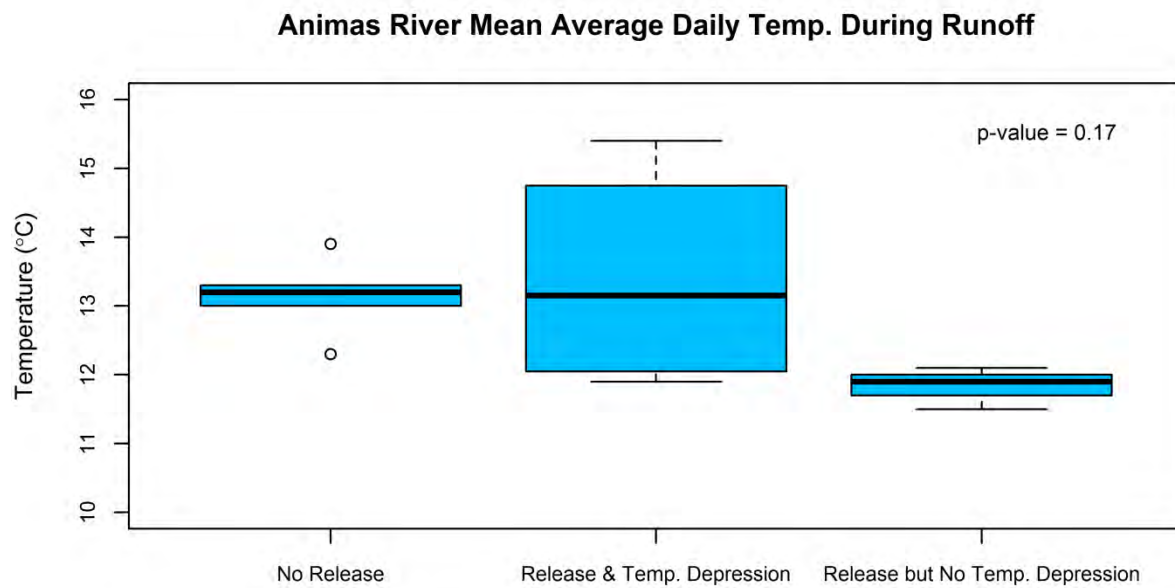
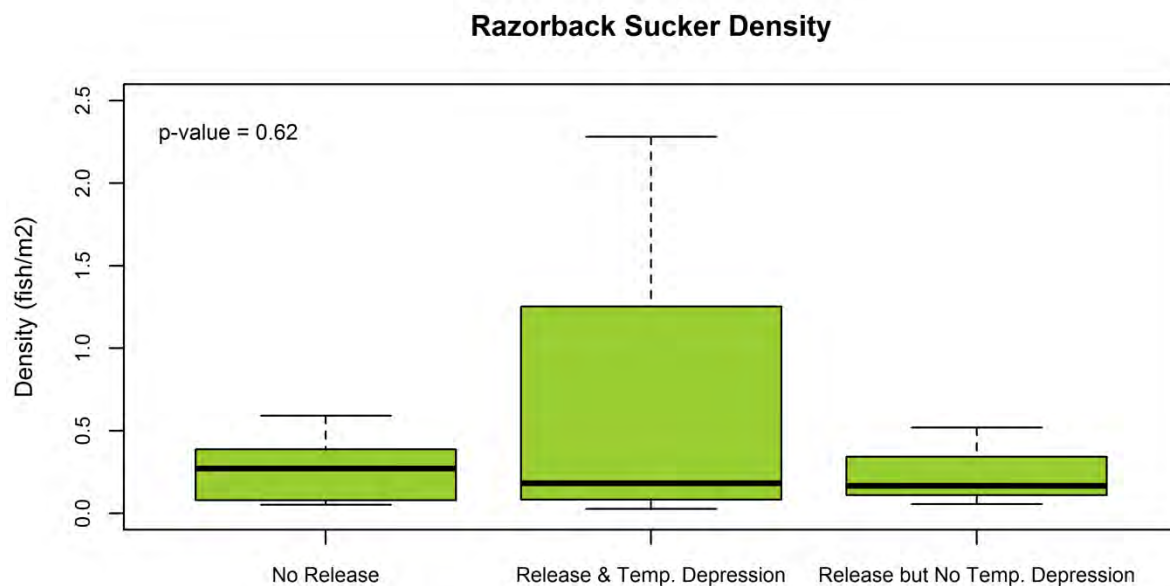


Figure 25. Comparison of mean average daily temperature during the runoff period at Archuleta. Open circles indicate data outliers.





**Figure 26. Comparison of mean average daily temperature during the runoff period for the Animas River. Open circles indicate data outliers.**



**Figure 27. Comparison of Razorback Sucker density for the three categories of releases.**

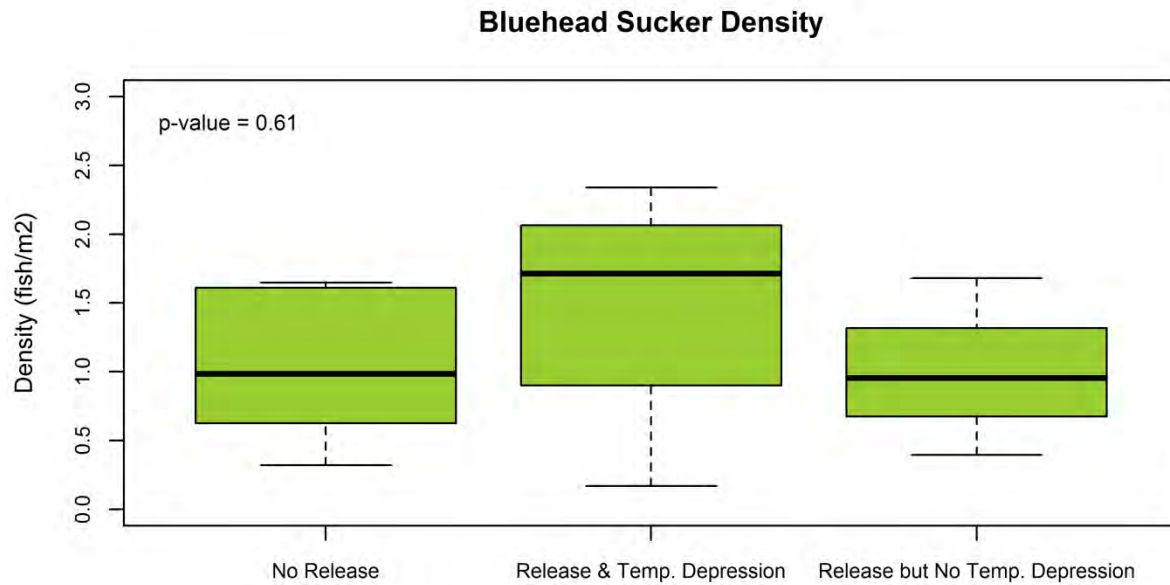


Figure 28. Comparison of Bluehead Sucker density for the three categories of releases.

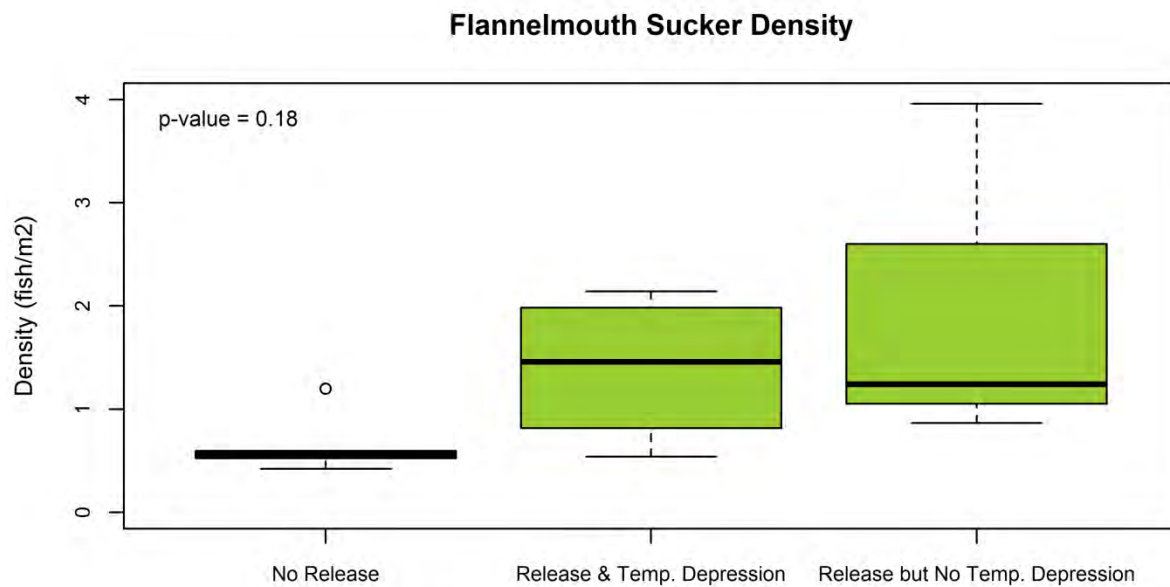


Figure 29. Comparison of Flannemouth Sucker density for the three categories of releases. Open circles indicate data outliers.

The ANOVA analyses compared fish densities to temperatures at Mexican Hat but did not find any significant differences between the categories of releases. We then considered whether other variables related to releases and water temperature could explain the differences in fish densities. Six variables were evaluated: the number of days (since the start of the year) for average daily temperature to reach 20°C at Mexican Hat; the number of days of temperature depression; the length of the release from Navajo Dam (in days); average daily temperature at Archuleta during the runoff; average daily temperature in the Animas River during runoff; and the average daily temperature at Mexican Hat during the runoff.

The 20°C threshold was chosen based on the results from a few studies. Marsh (1985) incubated embryos of Razorback Sucker, Humpback Chub *Gila cypha*, Bonytail *Gila elegans*, and Colorado Pikeminnow at 5, 10, 15, 20, 25 and 30°C. Total mortality of all species occurred in 12-96 hours at 5, 10 and 30°C and in 48-60 hours at 15°C for pikeminnow only. Marsh also found that spinal and other anomalies were more frequent at 15 and 25°C than at 20°C. In general, due to lower survival and higher incidence of anomalies at 15 and 25°C, Marsh concluded that optimal temperatures for hatching and development are likely near 20°C. Clarkson and Childs (2000) examined the effects of three temperatures (10°C, 14°C and 20°C) on growth, development and physiology of larval and early juvenile life stages of Razorback Sucker, Flannelmouth Sucker, Colorado Pikeminnow and Humpback Chub. They found that lengths, weights and growth rates of all species were significantly lower at 10°C and 14°C than at 20°C. The time to transformation from the larval to juvenile stages was also delayed at colder temperatures. Bestgen (2008) conducted laboratory experiments that estimated the growth of Razorback Sucker up to 37 days post-hatch. Warmer water temperatures (16.5 –25.5°C) were assessed to simulate conditions in the Green River floodplain wetlands, where water temperatures exceed 20-25°C by late June. Razorback Sucker growth was positively related to water temperature. Larvae reared at 25.5°C grew about twice as fast in length as those at 16.5°C and growth was intermediate at 19.5°C and 22.5°C. Bestgen found that the positive effect of temperature on growth was particularly noticeable when temperatures were 19.5°C or higher. The time required for sucker larvae to exceed 25 mm total length, a potentially important threshold for reduced predation, was 30 days (post-hatch) at 25.5°C and 41 days at 16.5°C.

A correlation analysis was first performed on the six predictor variables to determine if any of the variables were highly correlated. Highly-correlated variables can lead to problems in model prediction (multicollinearity). Length of release was highly correlated ( $r > 0.80$ ) with three of the variables and was subsequently removed from further analyses. Average daily temperature at Archuleta was highly correlated with three of the variables and was also removed.

We performed all-subsets regressions, in which all possible combinations of predictor variables are tested for significance. For Razorback Sucker density, average daily temperature during the runoff in the Animas River and at Mexican Hat were found to be the most important predictor

variables, but regression diagnostics revealed that results were influenced by a single observation. When that observation was removed, none of the variable combinations were significant predictors of Razorback Sucker density (the largest adjusted  $R^2$  value was 0.15). For Bluehead Sucker, none of the variable combinations were significant predictors of density (the largest adjusted  $R^2$  value was 0.15). For Flannemouth Sucker, there was a positive relationship between density and days of temperature depression. However, while the relationship was significant ( $p = 0.008$ ), the adjusted  $R^2$  value was only 0.52.

## DISCUSSION

We were unable to detect a relationship between the San Juan River at Mexican Hat temperature regime and larval fish densities of Razorback Sucker, Bluehead Sucker or Flannemouth Sucker. The timing of larval collections did not coincide with depressions in water temperature in the San Juan River in most years. Larval drift sampling in the 1990s was not initiated in most years until after runoff or late in the descending limb of runoff. Larval seining in the 2000s was conducted on a weekly basis and usually occurred both before and after runoff. The larval collections did detect reproduction by both Colorado Pikeminnow and Razorback Sucker, however, no correlation between water temperature and larval density of either species could be detected. Concurrent sampling for larvae and water temperature may be needed to provide a more robust data set to test for effects of water temperature depression on larval endangered species in the San Juan River. Research on both species suggests that altered water temperature regimes due to dam releases could be detrimental to both species.

Razorback Sucker spawning has been related to the ascending limb of the spring hydrograph, peak spring discharge and warming river temperatures and coincides with the spawning times of other native catostomids (Farrington et al. 2013). Spawning has been documented from mid-April to early June in the Green River (Tyus and Karp 1990). The most recent larval surveys have determined that, through back-calculation of hatching dates, that Razorback Sucker larvae hatch between early April and early June in the San Juan River (Brandenburg et al. 2012, Farrington et al. 2013). Bestgen et al. (2011) provided a synthesis of Razorback Sucker reproduction from 1993 to 2008 in the Green River as related to stream discharge, water temperature and floodplain wetland availability. Results indicated that spawning occurred as the water warmed but nearly always happened before mean daily water temperature exceeded 14°C. If the same relationship exists within the San Juan River, then it seems likely that Razorback Sucker spawning is not affected by the coldwater releases since mean daily water temperatures have reached 14°C by the time the runoff begins for all years (refer to figures in Appendix A).

Razorback Sucker could be experiencing reduced hatching success and/or reduced larval survival due to slower growth rates at lower water temperatures. In 9 of the 12 years we evaluated,  $\geq 97\%$

of Razorback Sucker larvae were captured before or as the runoff period ended. Yet this occurred regardless of whether there was a release and, in fact, two of the years in which larvae were captured after the runoff period ended were years that had releases (one year saw a temperature depression effect while the other did not). Marsh (1985) reported that anomalies and spinal deformities in Razorback Sucker protolarvae were higher at 15 °C than at 20 °C.

Flannelmouth Sucker and Bluehead Sucker also spawn before or near peak runoff in both regulated and unregulated rivers. There was not correlation with water temperature depression and spawning and larval abundance by either species in the San Juan River. It is unknown if there the water temperature depression caused by releases from Navajo Reservoir impact growth or survival of either species.

The low number of larval Colorado Pikeminnow captured over the period of recorded examined for this report precluded inclusion of that species in the analysis. There is evidence of natural reproduction and recruitment since closure of Navajo Dam in 1963, although the at low levels. Meyer and Moretti (1988), Platania (1990), Platania et al. (1991) and Roberts and Moretti (1989) reported adult Colorado Pikeminnow present in collections that ranged from Lake Powell up to near Shiprock, New Mexico. They also reported young of the year (YOY) Colorado Pikeminnow in collections from Lake Powell inflow up to Montezuma Creek, New Mexico. Ryden and Pfiefer 1994 report adult Colorado Pikeminnow in San Juan River captures. Lashmitt (1994) reported YOY Colorado Pikeminnow in collections from low velocity habitats in the lower San Juan River. Recent larval collections have documented Colorado Pikeminnow reproduction in the San Juan River. The numbers of larvae collected are too low and too infrequent to include in the statistical analysis conducted for this retrospective analysis.

Change in water temperature regimes as a result of reservoir releases has long been a focus of research on Colorado Pikeminnow. Kaeding et al. (1986) hypothesized that cooler water temperature from reservoir releases could be a limiting factor for Colorado Pikeminnow. Kaeding and Osmundson (1988) hypothesized that the interaction of slow growth and increased mortality on YOY Colorado Pikeminnow from cooler water temperature regimes could one cause in the decline of the species. Black and Bulkley (1985a) found the optimal growth rate for yearling Colorado Pikeminnow was 25°C. Black and Bulkley (1985b) reported the preferred temperature of yearling Colorado Pikeminnow was 25°C. These temperatures are reached in the San Juan River, however at a later date than occurred historically. The reduced amount of time when these temperatures occur could be resulting in Colorado Pikeminnow entering winter at a smaller size and less fit than under a more natural water temperature regime.

Berry (1988) reported increased mortality and behavioral changes in 14 day old Colorado Pikeminnow larvae subjected to cold shocks of 5°C, 10°C, and 15°C. Berry and Pimintel (1985) reported that juvenile Colorado Pikeminnow had lower swimming stamina at lower water

temperatures when compared with warmer water temperatures. Childs and Clarkson (1996) concluded that cold hypolimnetic release from dams significantly reduced swimming ability of YOY Colorado Pikeminnow and may partially explain the decline in the species. Bestgen and Williams (1994) reported that high water temperatures (30°C) resulted in increased mortality and abnormalities in larval Colorado Pikeminnow. They also report the highest hatch of Colorado Pikeminnow occurred at 18°C, 22°C, and 26°C.

Muth et al. (2000) highlighted water temperature as a factor that may be limiting to endangered species in the upper Colorado River Basin. Specific water temperature recommendations were made regarding flow recommendations for Flaming Gorge Reservoir. They developed six objectives related to flow and temperature recommendations. Objectives 1 and 6 apply to water temperature and are as follows:

*“(1) provide appropriate conditions that allow gonadal maturation and environmental cues for spawning movements and reproduction; (6) minimize differences in water temperature between the Green River and Yampa River in Echo Park to prevent temperature shock and possible mortality to larval Colorado pikeminnow transported from the Yampa River and into the Green River during summer.”*

This retrospective analysis of water temperature data for the San Juan River at Mexican Hat and larval fish survey data did not document a direct link between coldwater releases from Navajo Dam and numbers of Razorback Sucker larvae. Further, the available data sets for larvae do not have data on growth or overwinter survival for additional analyses of water temperature. Additional work would be needed to measure the larvae in the UNM collection for other type of analyses and is beyond the scope of this retrospective report.

There is an extensive body of previous research that would suggest that a natural water temperature regime is beneficial to the native fish community including the endangered species and water temperature criteria should be part of a revised flow recommendation. The amount of water temperature control from Navajo Dam is limited due to the hypolimnetic release. Future research and any revised flow recommendations should consider means to mimic not only a natural hydrograph but also the water temperature characteristics of a natural flow regime in the San Juan River.

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## **APPENDIX A**

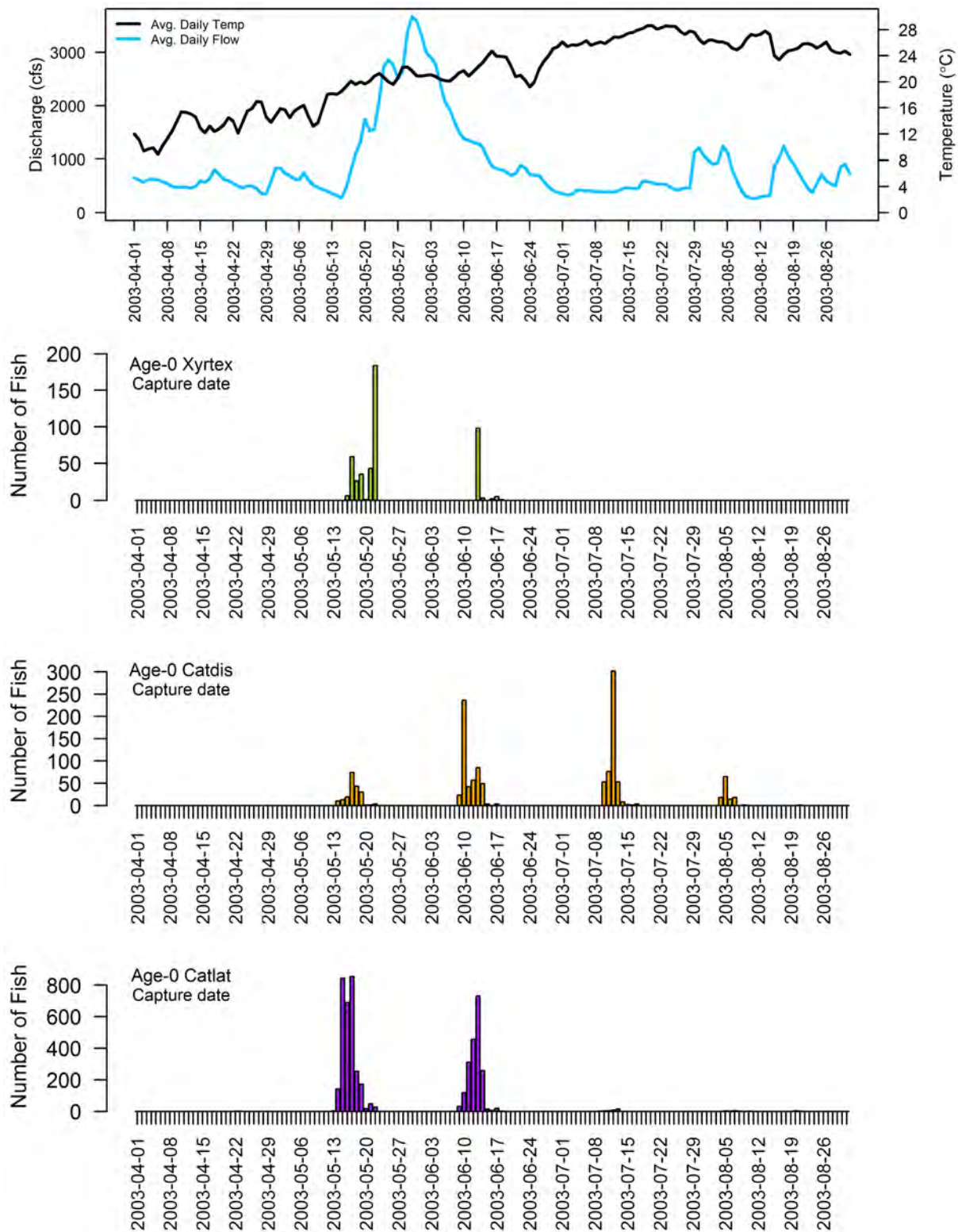
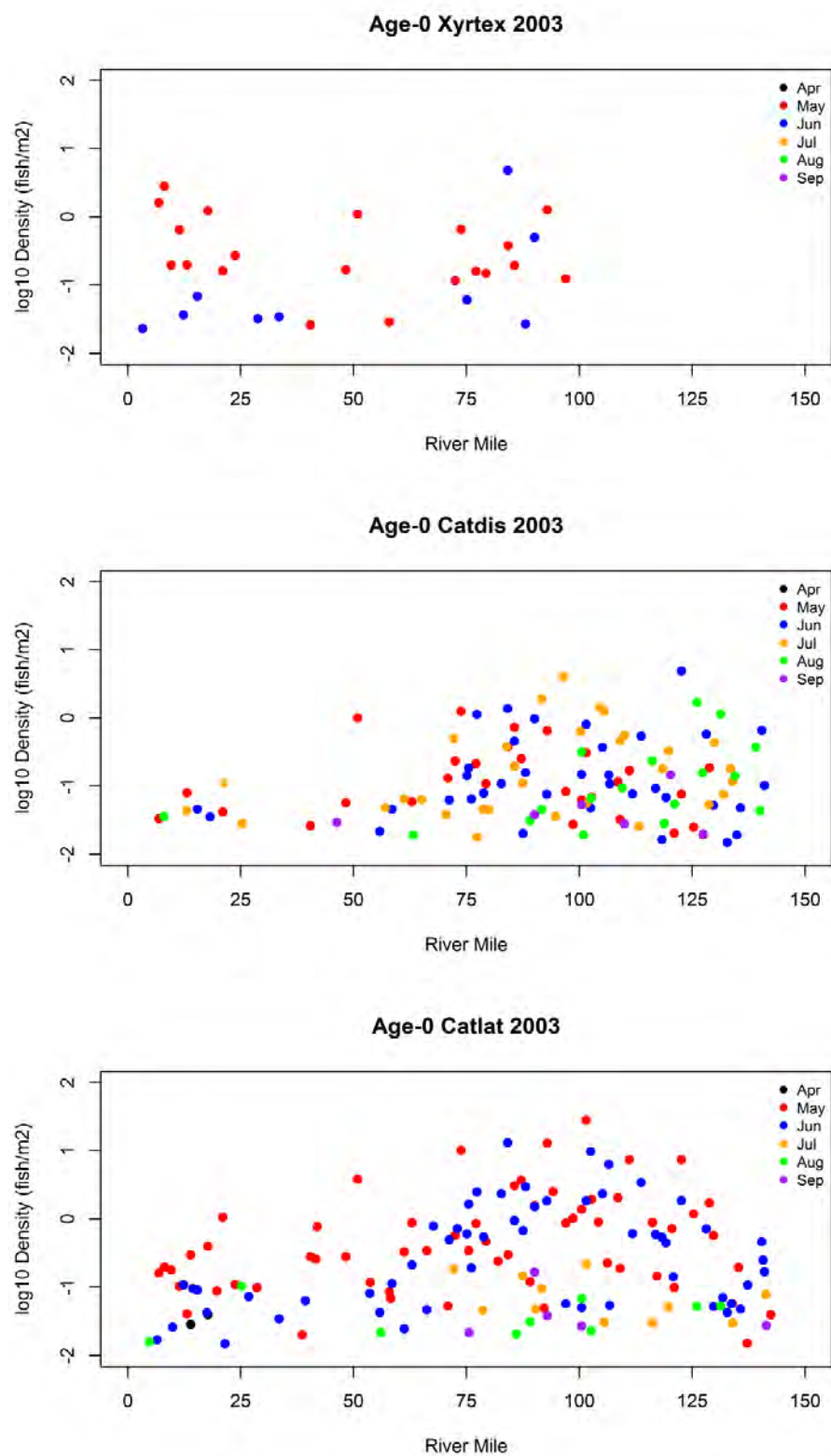
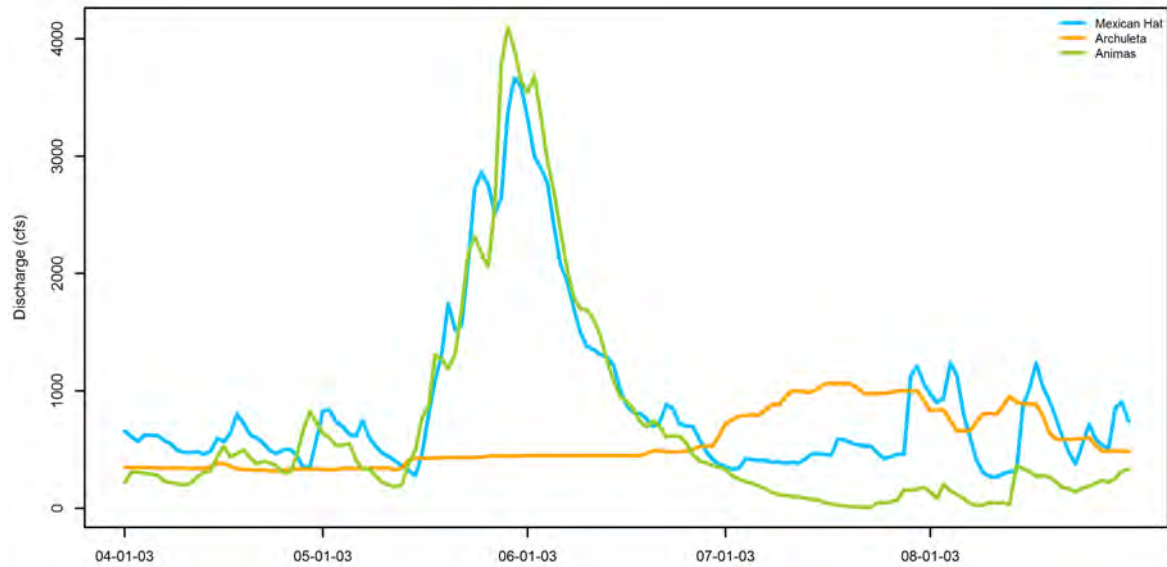


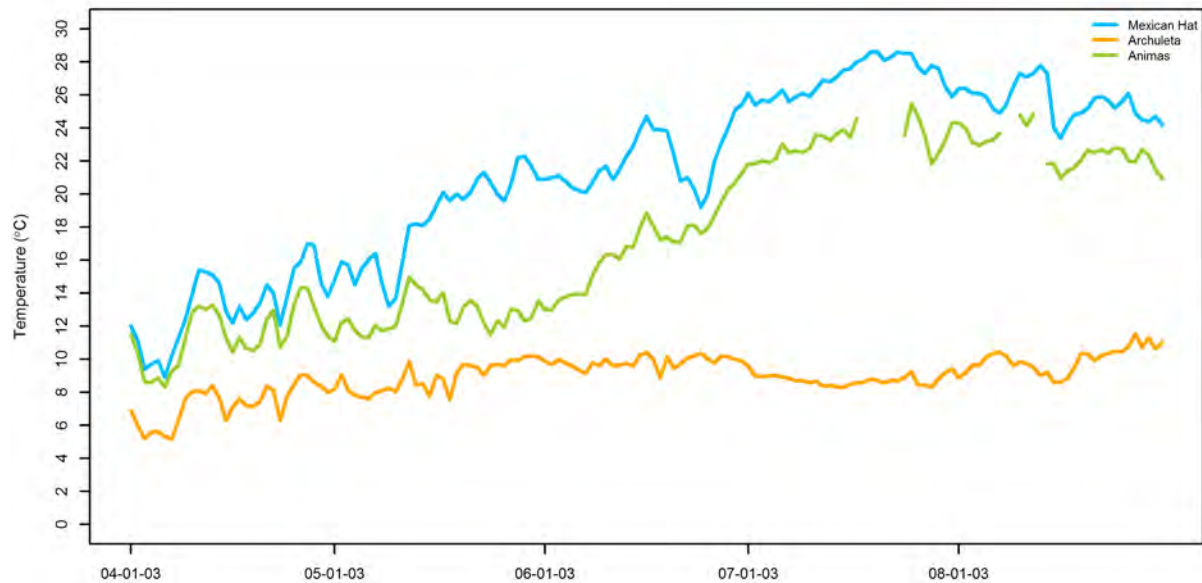
Figure A-1. Capture data for Razorback Sucker, Bluehead Sucker and Flannelmouth Sucker larvae, along with average daily temperature and average daily flow for the San Juan River at Mexican Hat, 2003.



**Figure A-2. Months and locations in which Razorback Sucker, Bluehead Sucker and Flannelmouth Sucker larvae were captured, 2003.**



**Figure A-3. Average daily flow for the San Juan River at Archuleta and Mexican Hat and the Animas River at its confluence with the San Juan River, 2003.**



**Figure A-4. Average daily temperature for the San Juan River at Archuleta and Mexican Hat and the Animas River at its confluence with the San Juan River, 2003.**



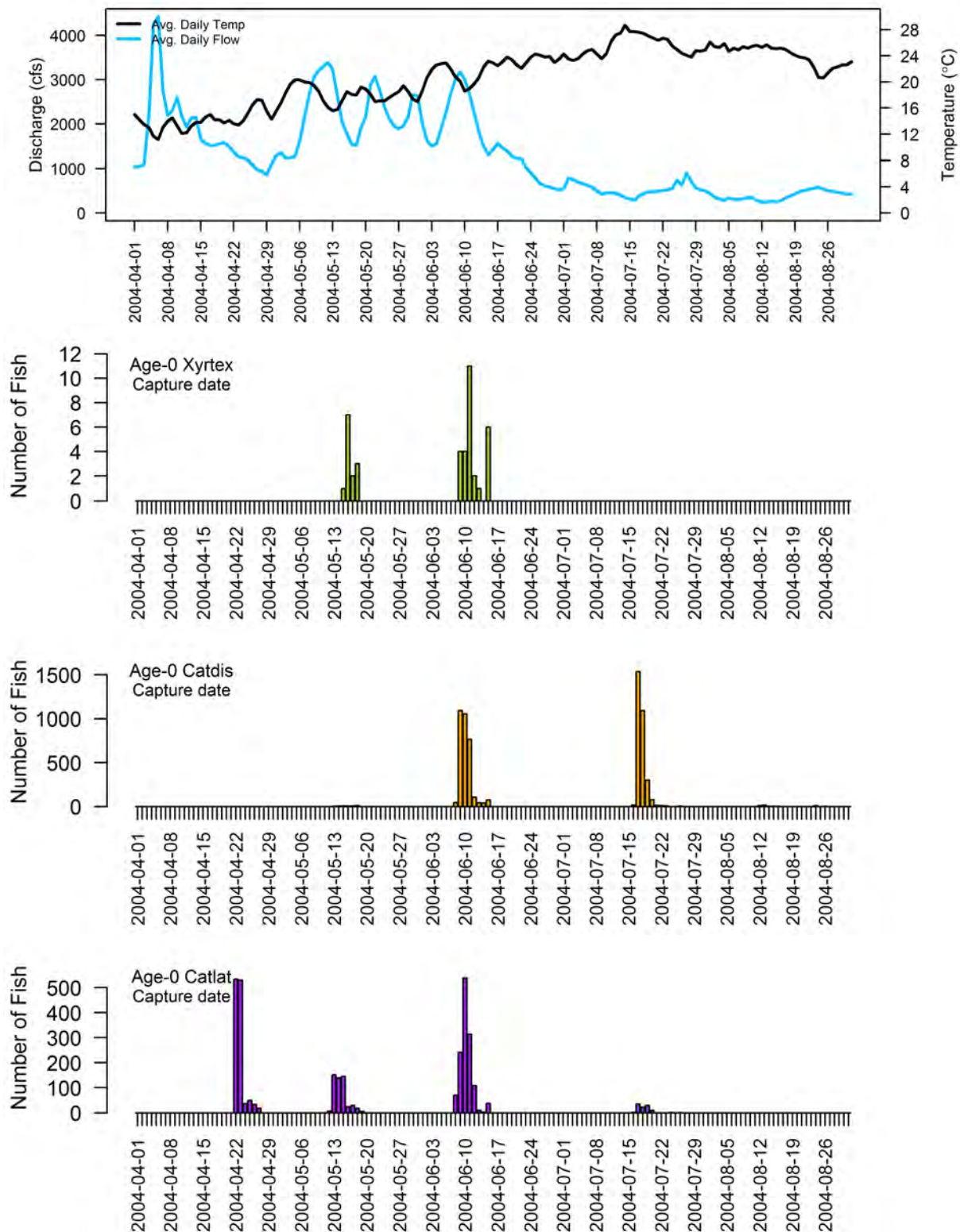
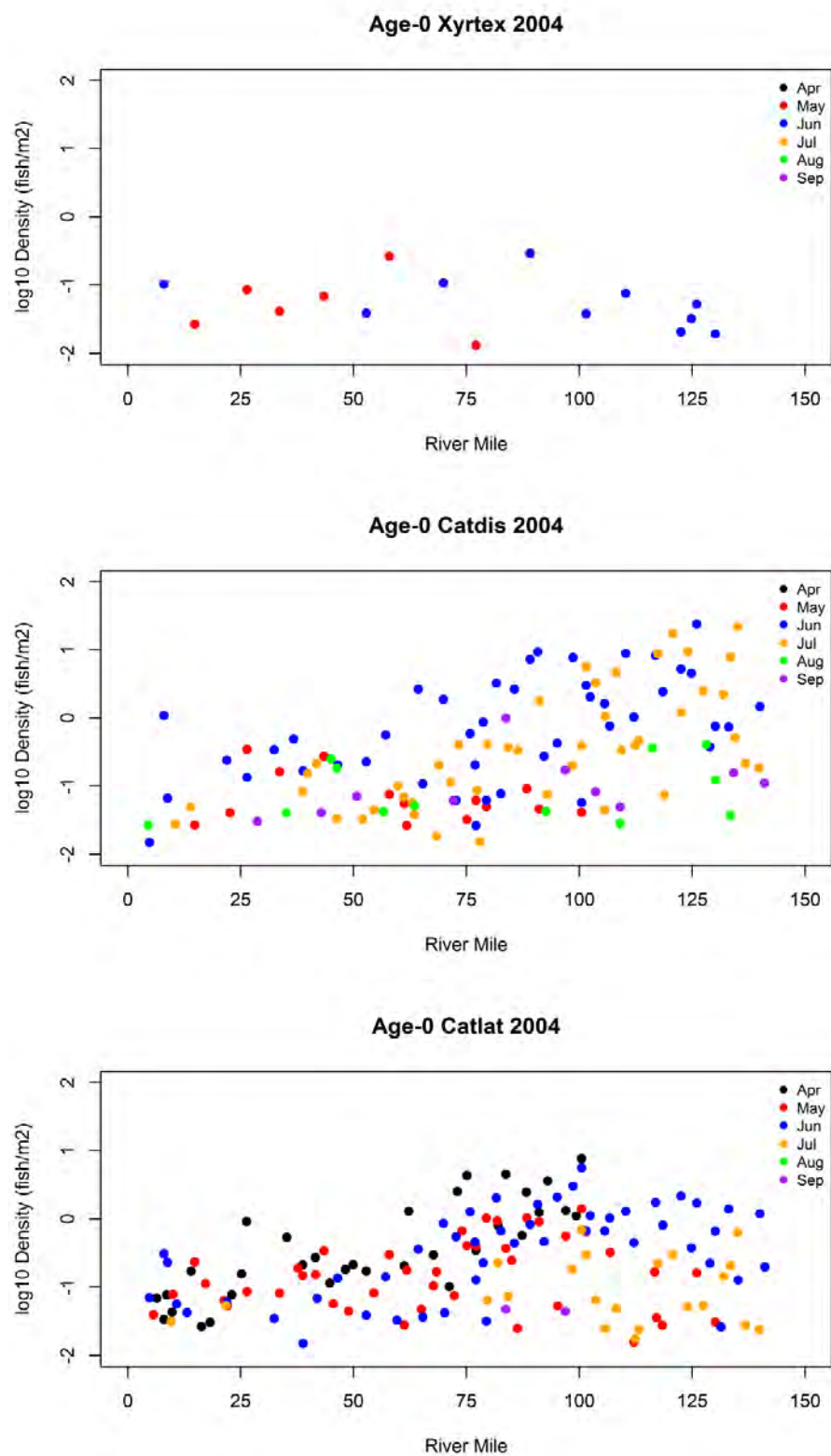
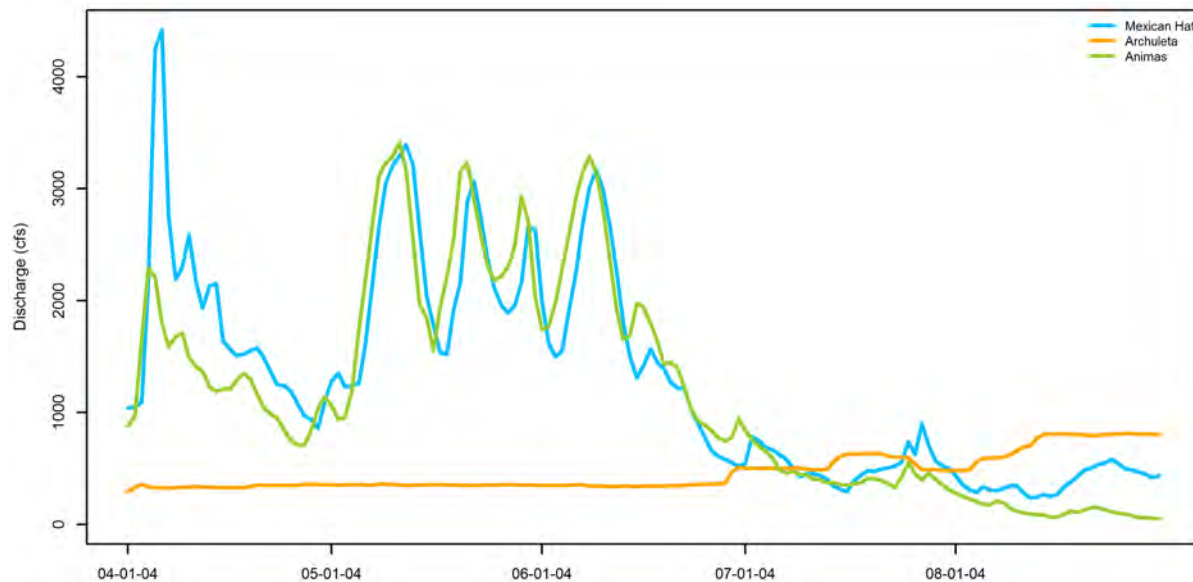


Figure A-5. Capture data for Razorback Sucker, Bluehead Sucker and Flannelmouth Sucker larvae, along with average daily temperature and average daily flow for the San Juan River at Mexican Hat, 2004.

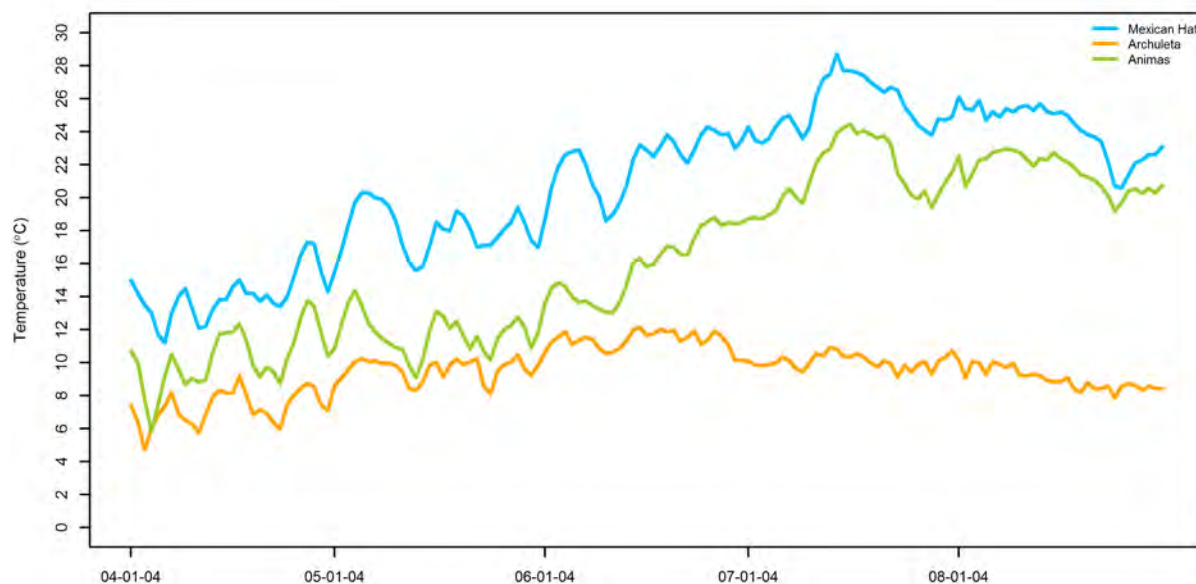


**Figure A-6. Months and locations in which Razorback Sucker, Bluehead Sucker and Flannelmouth Sucker larvae were captured, 2004.**





**Figure A-7. Average daily flow for the San Juan River at Archuleta and Mexican Hat and the Animas River at its confluence with the San Juan River, 2004.**



**Figure A-8. Average daily temperature for the San Juan River at Archuleta and Mexican Hat and the Animas River at its confluence with the San Juan River, 2004.**

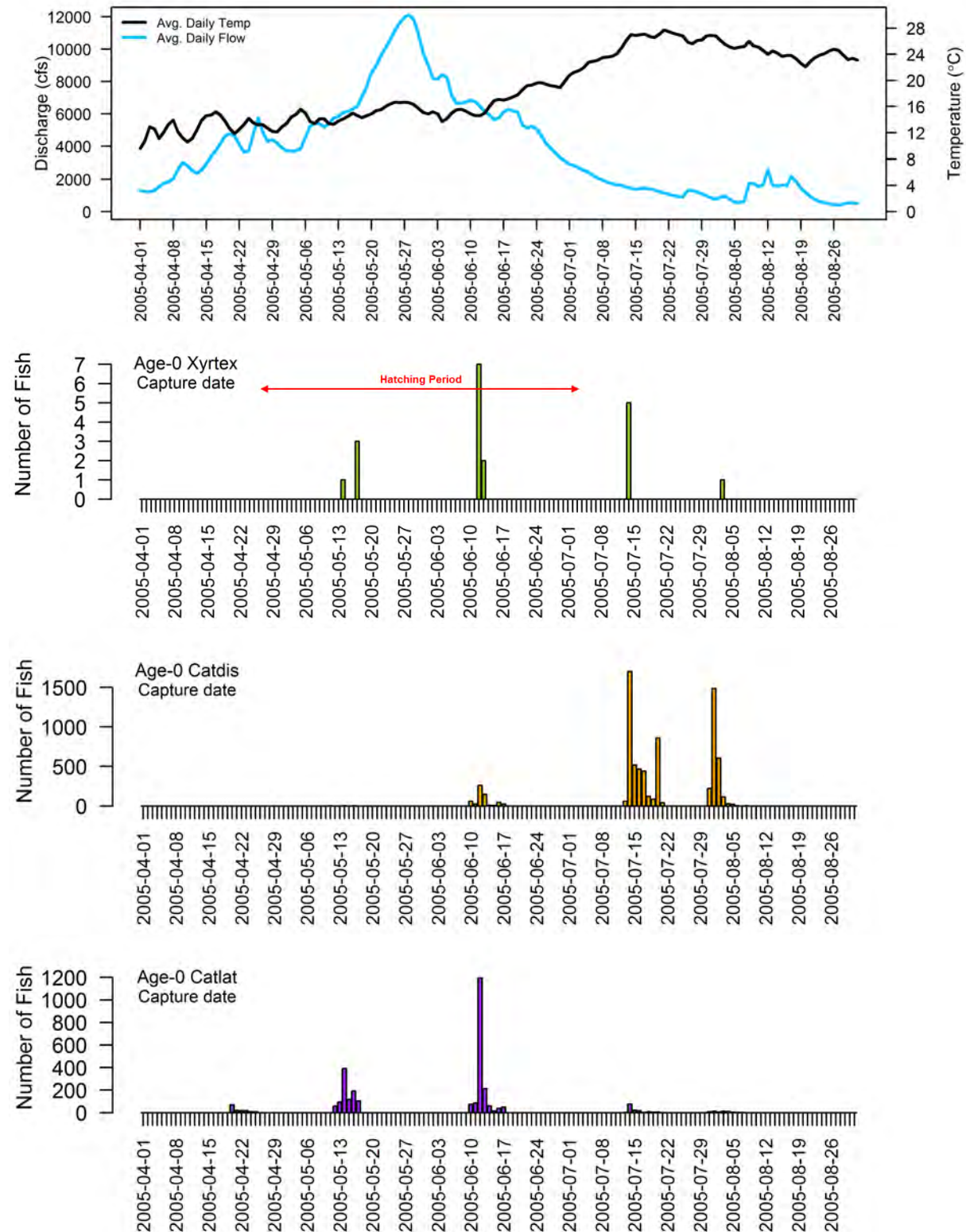
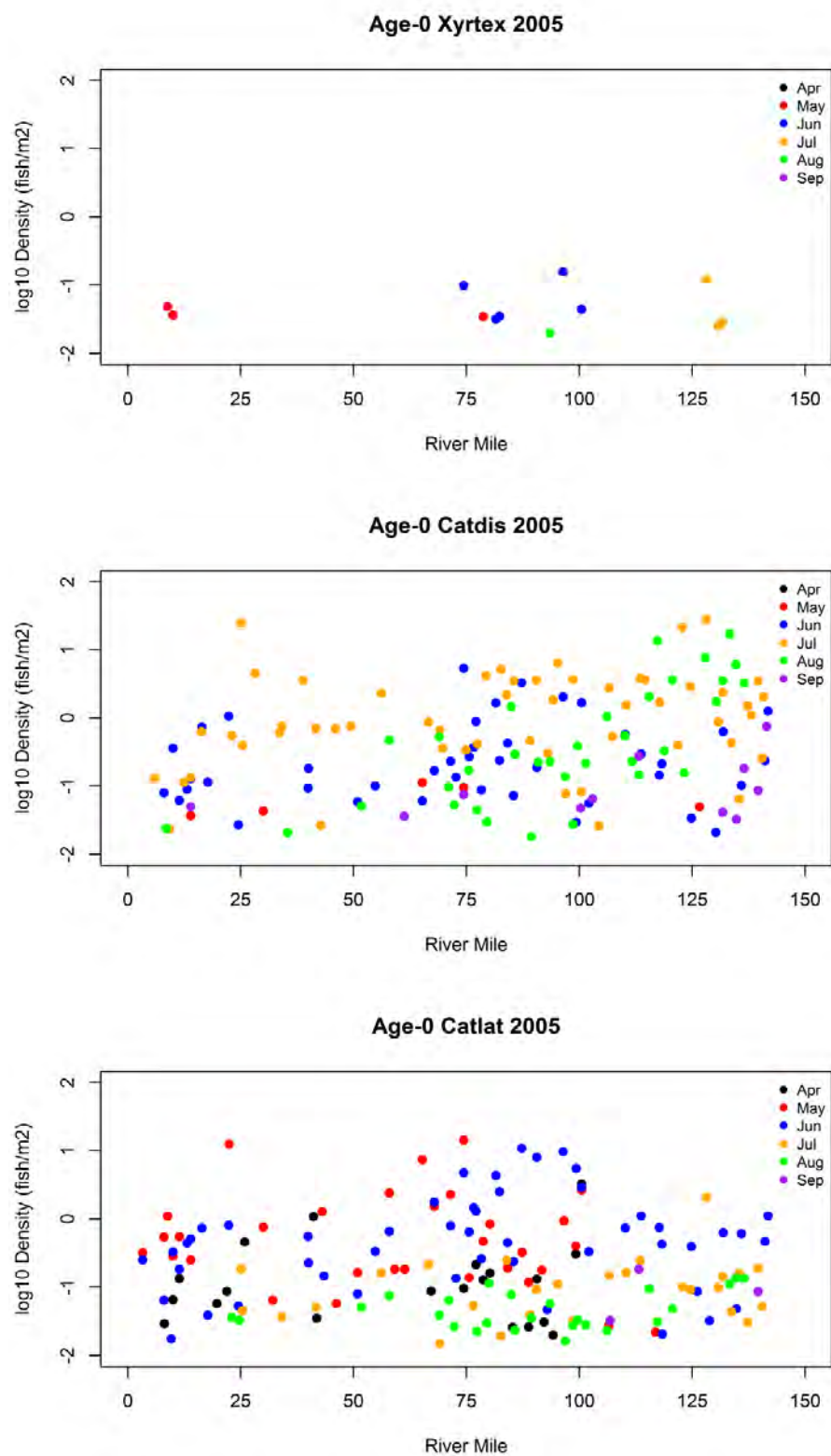
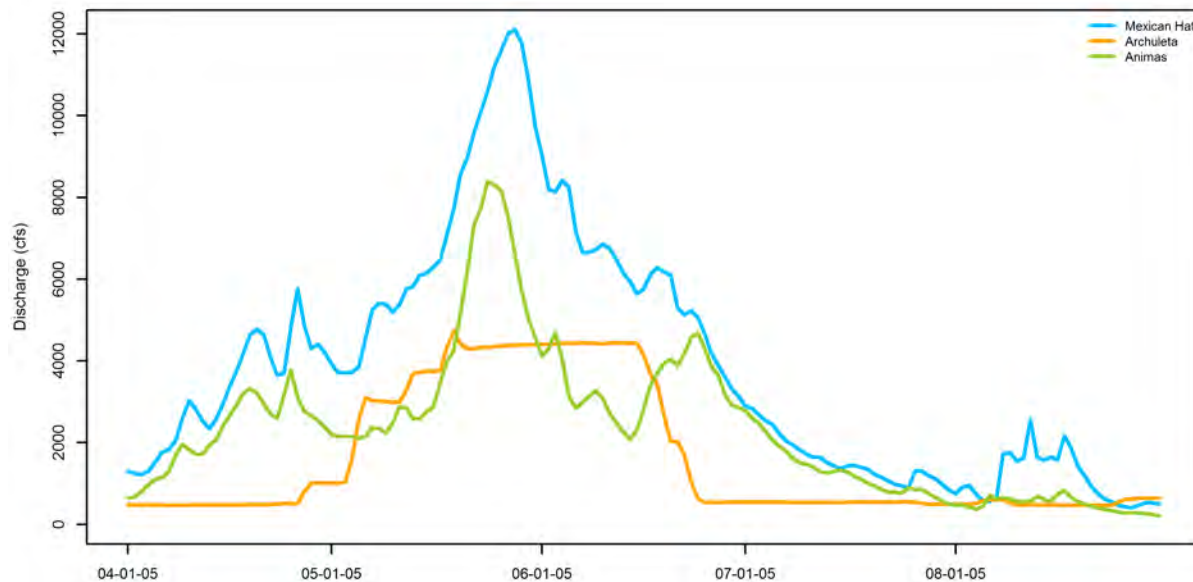


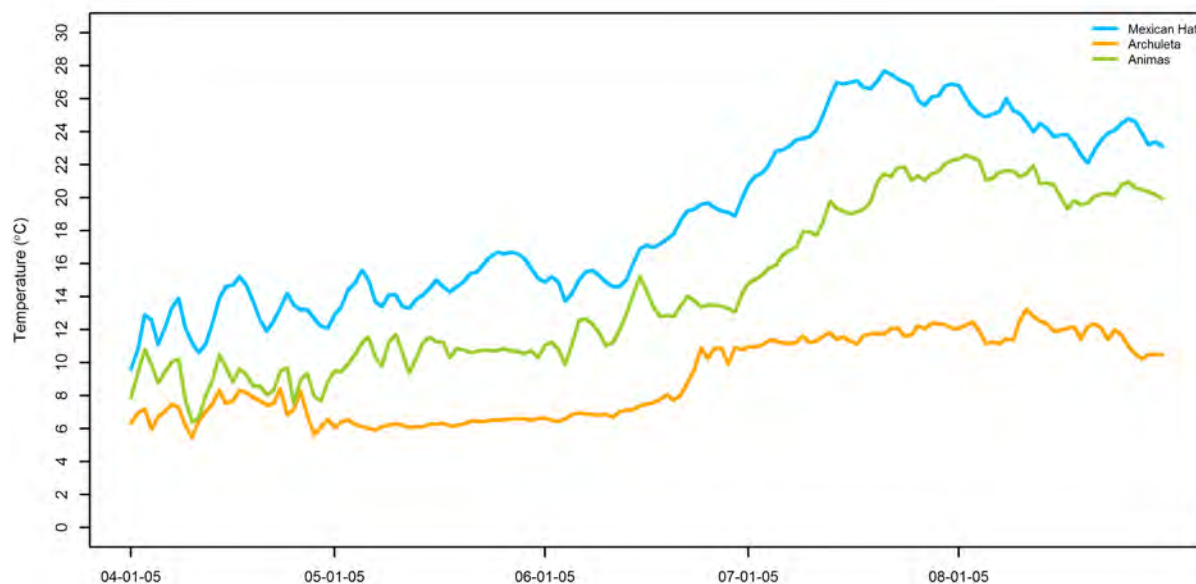
Figure A-9. Capture data for Razorback Sucker, Bluehead Sucker and Flannelmouth Sucker larvae, along with average daily temperature and average daily flow for the San Juan River at Mexican Hat, 2005.



**Figure A-10. Months and locations in which Razorback Sucker, Bluehead Sucker and Flannelmouth Sucker larvae were captured, 2005.**



**Figure A-11. Average daily flow for the San Juan River at Archuleta and Mexican Hat and the Animas River at its confluence with the San Juan River, 2005.**



**Figure A-12. Average daily temperature for the San Juan River at Archuleta and Mexican Hat and the Animas River at its confluence with the San Juan River, 2005.**



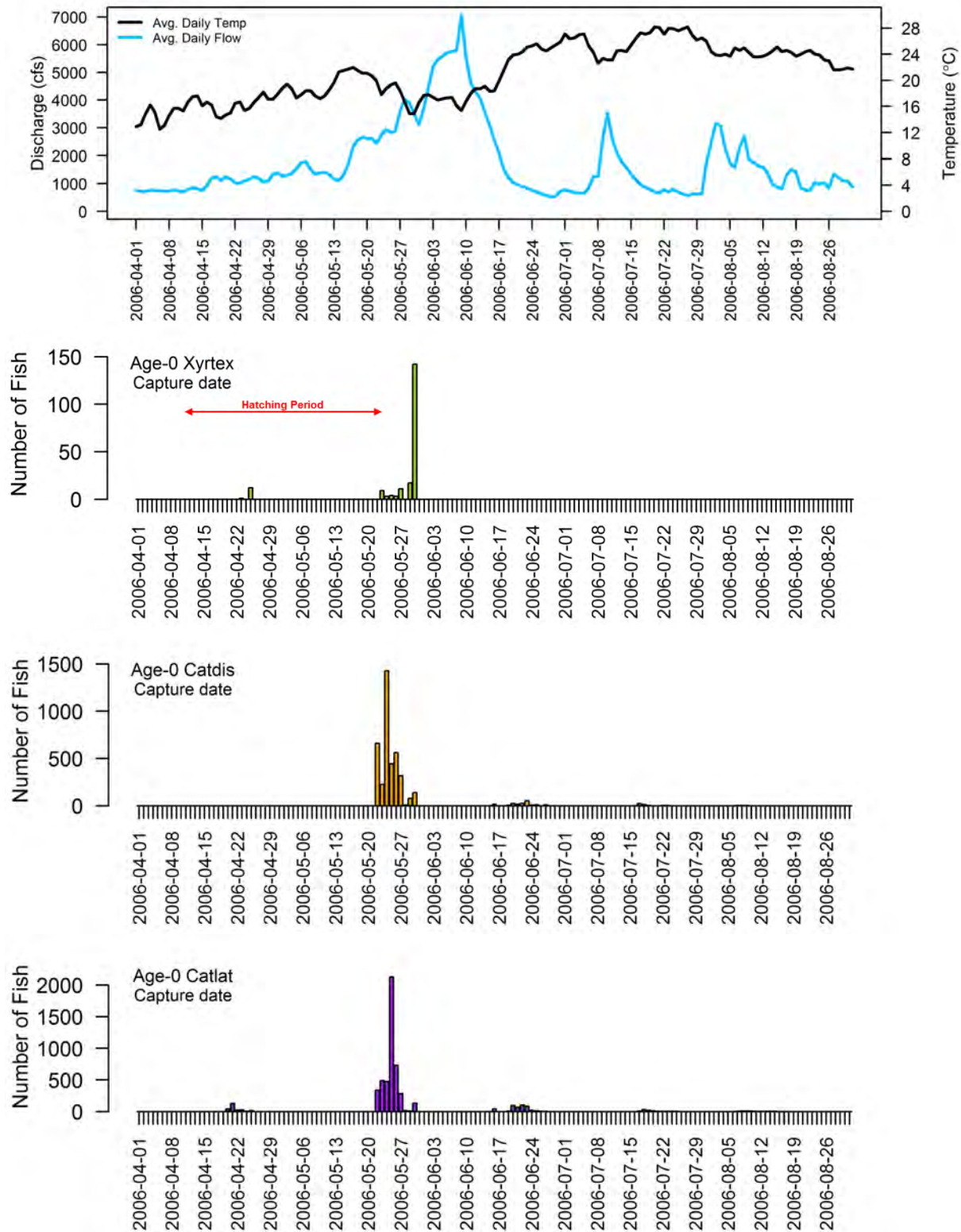
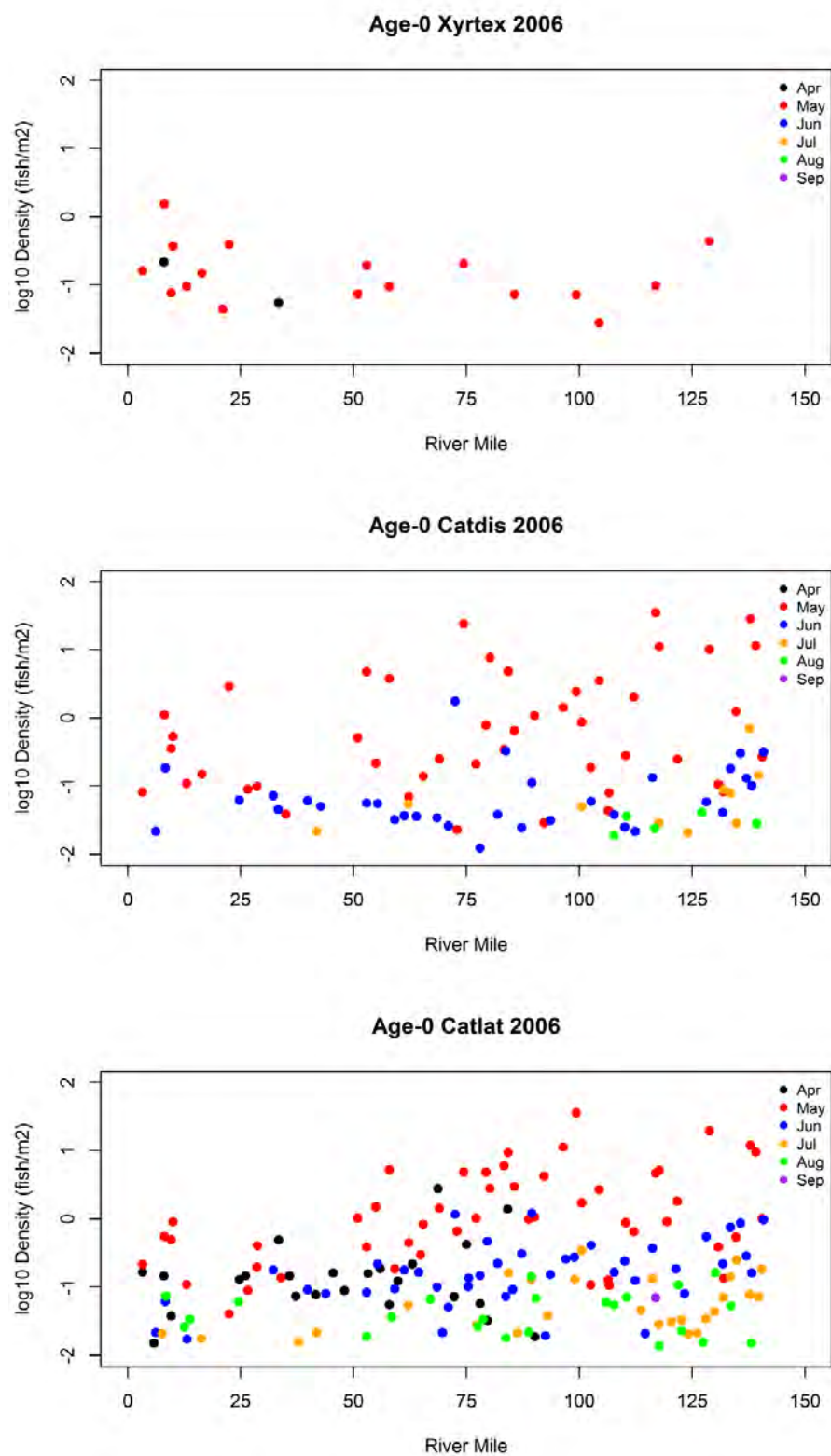
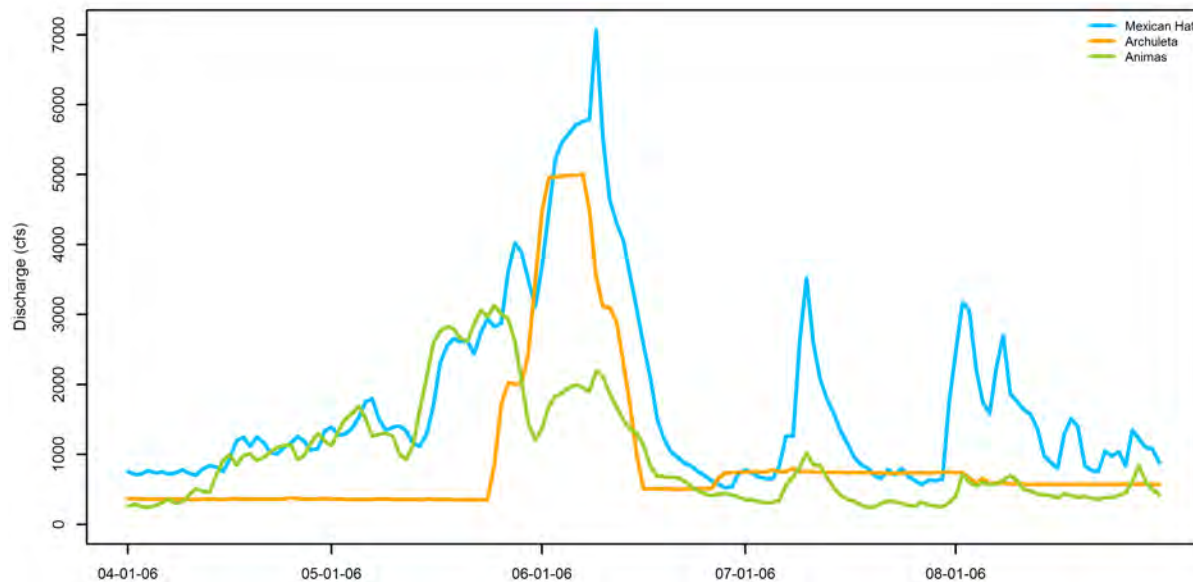


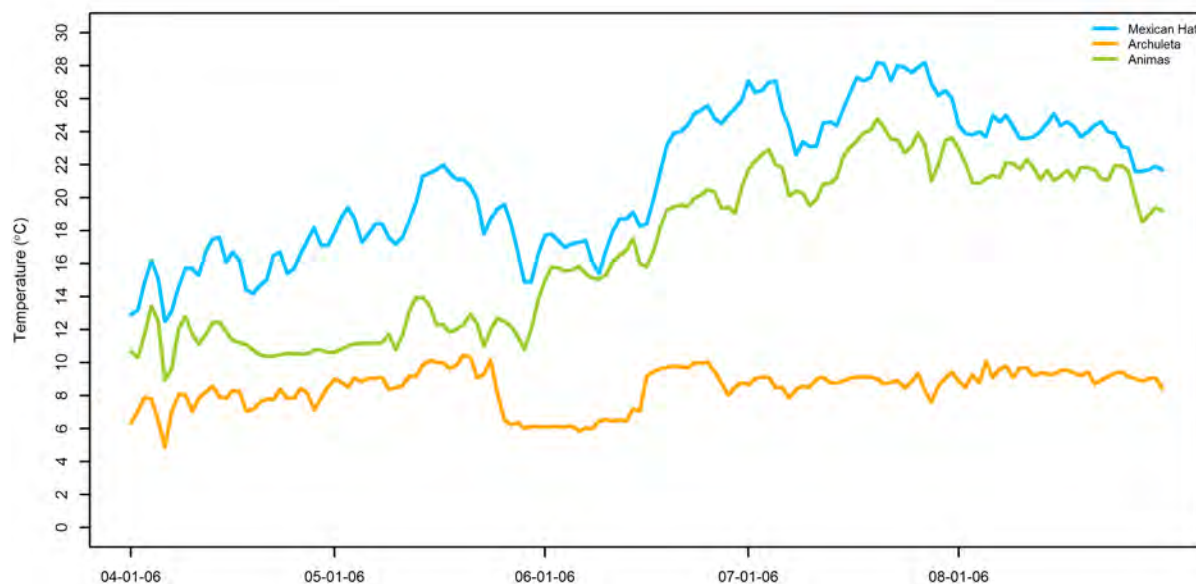
Figure A-13. Capture data for Razorback Sucker, Bluehead Sucker and Flannelmouth Sucker larvae, along with average daily temperature and average daily flow for the San Juan River at Mexican Hat, 2006.



**Figure A-14. Months and locations in which Razorback Sucker, Bluehead Sucker and Flannelmouth Sucker larvae were captured, 2006.**



**Figure A-15. Average daily flow for the San Juan River at Archuleta and Mexican Hat and the Animas River at its confluence with the San Juan River, 2006.**



**Figure A-16. Average daily temperature for the San Juan River at Archuleta and Mexican Hat and the Animas River at its confluence with the San Juan River, 2006.**

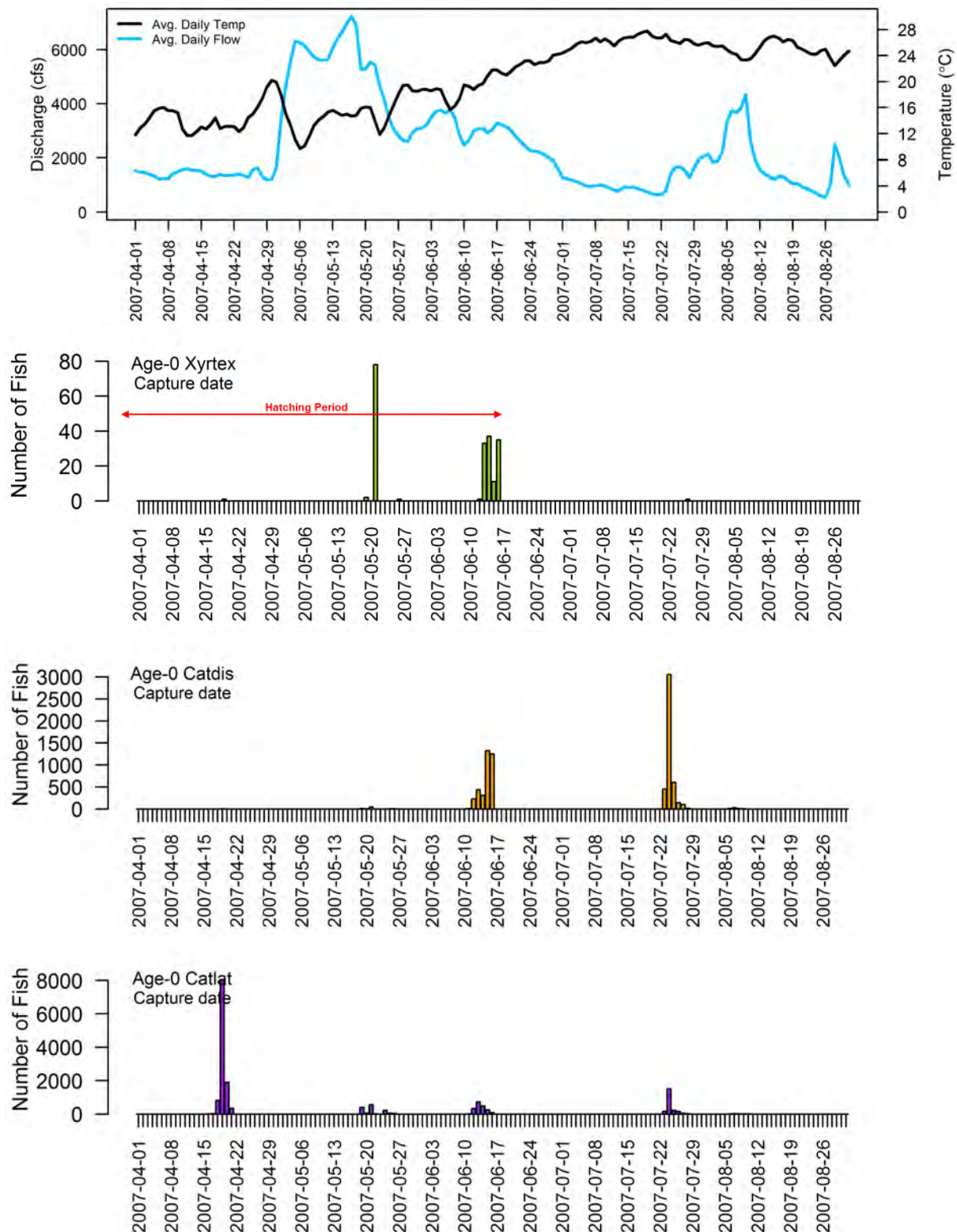
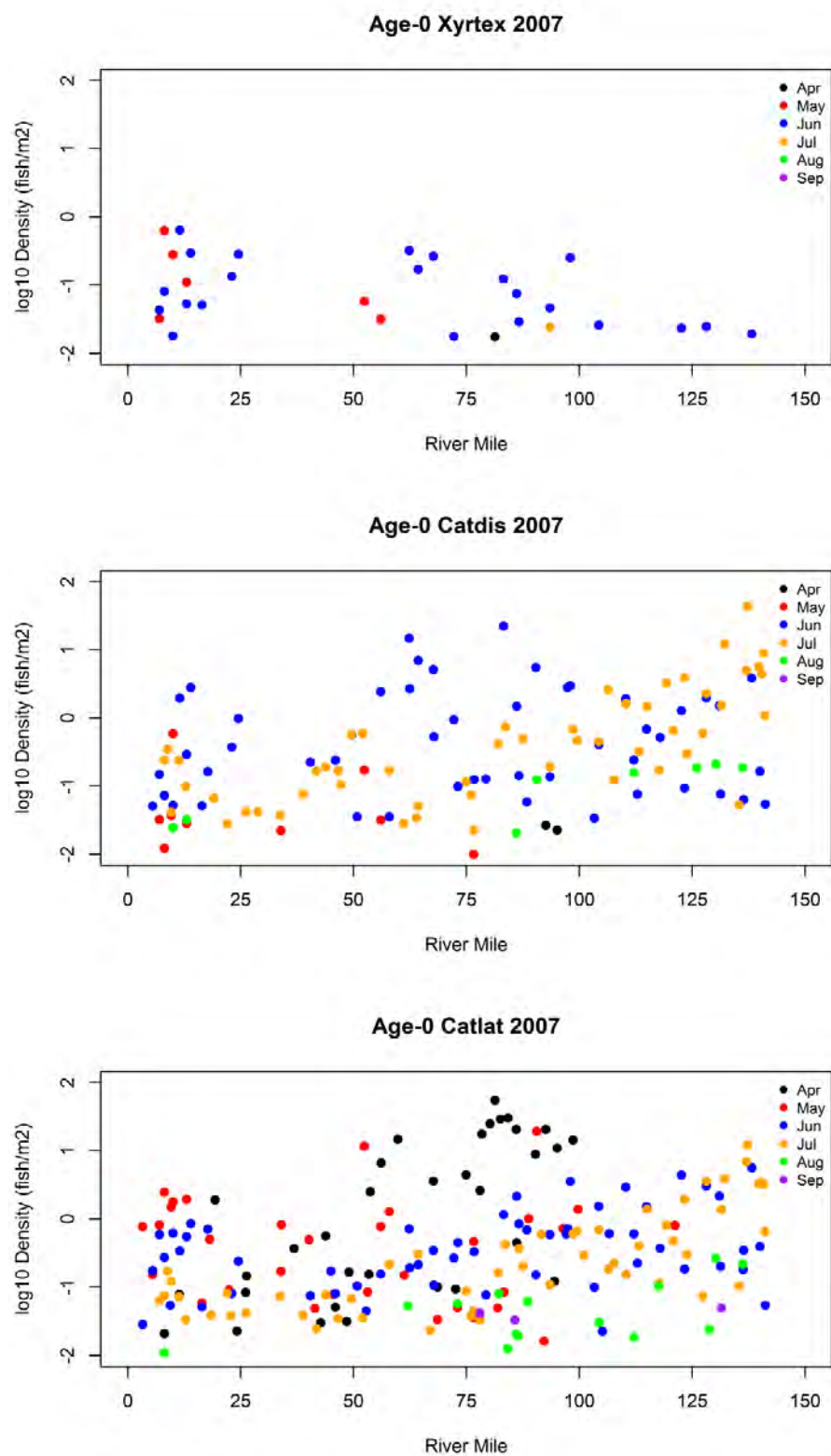
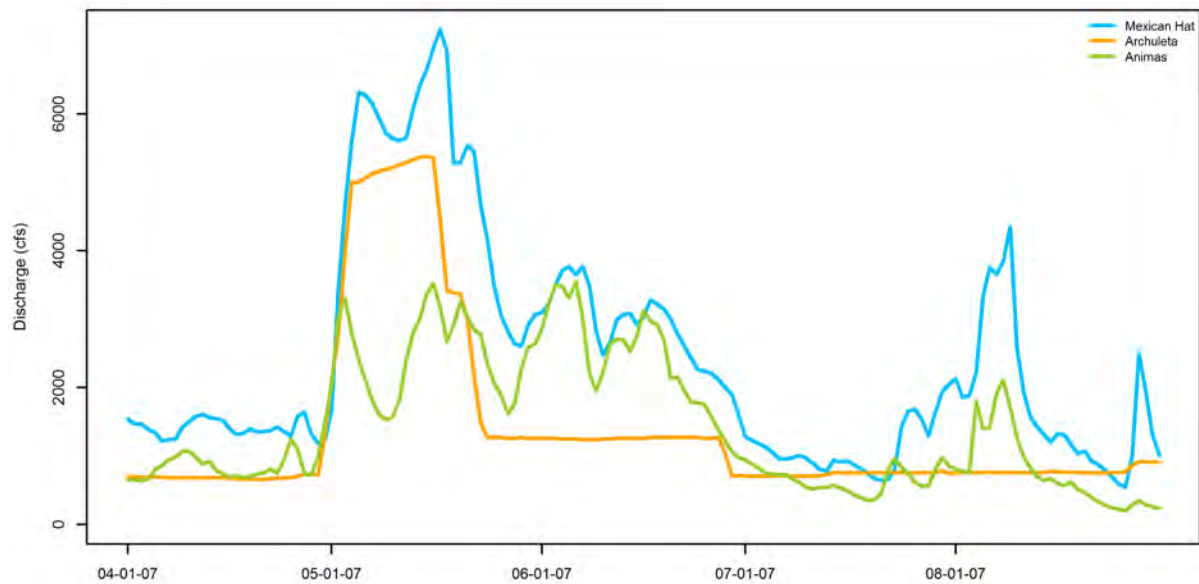


Figure A-17. Capture data for Razorback Sucker, Bluehead Sucker and Flannelmouth Sucker larvae, along with average daily temperature and average daily flow for the San Juan River at Mexican Hat, 2007.

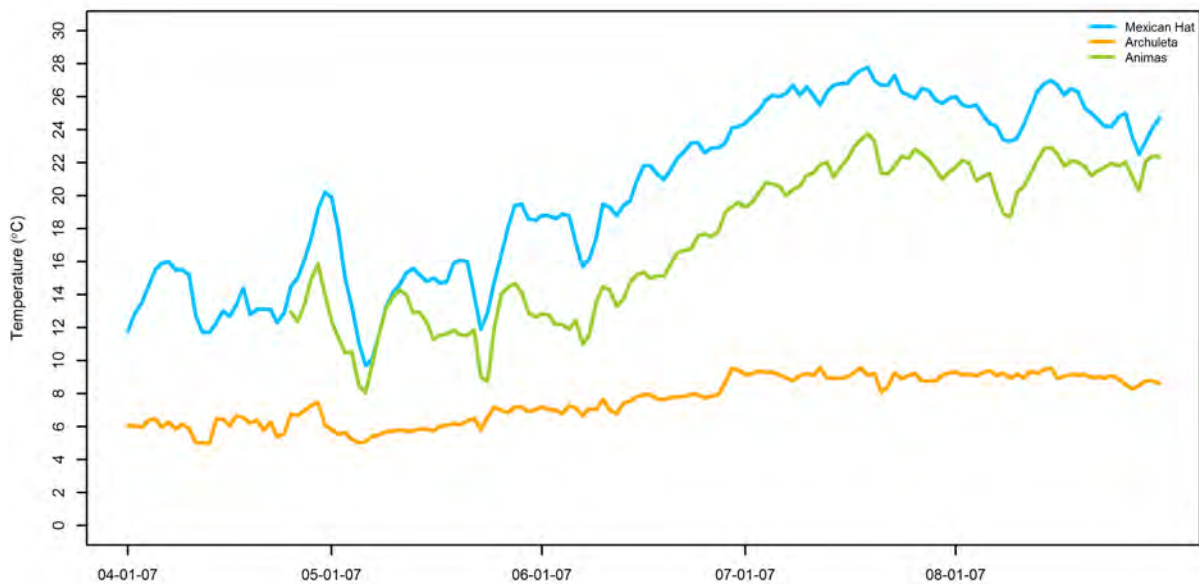




**Figure A-18. Months and locations in which Razorback Sucker, Bluehead Sucker and Flannelmouth Sucker larvae were captured, 2007.**



**Figure A-19. Average daily flow for the San Juan River at Archuleta and Mexican Hat and the Animas River at its confluence with the San Juan River, 2007.**



**Figure A-20. Average daily temperature for the San Juan River at Archuleta and Mexican Hat and the Animas River at its confluence with the San Juan River, 2007.**

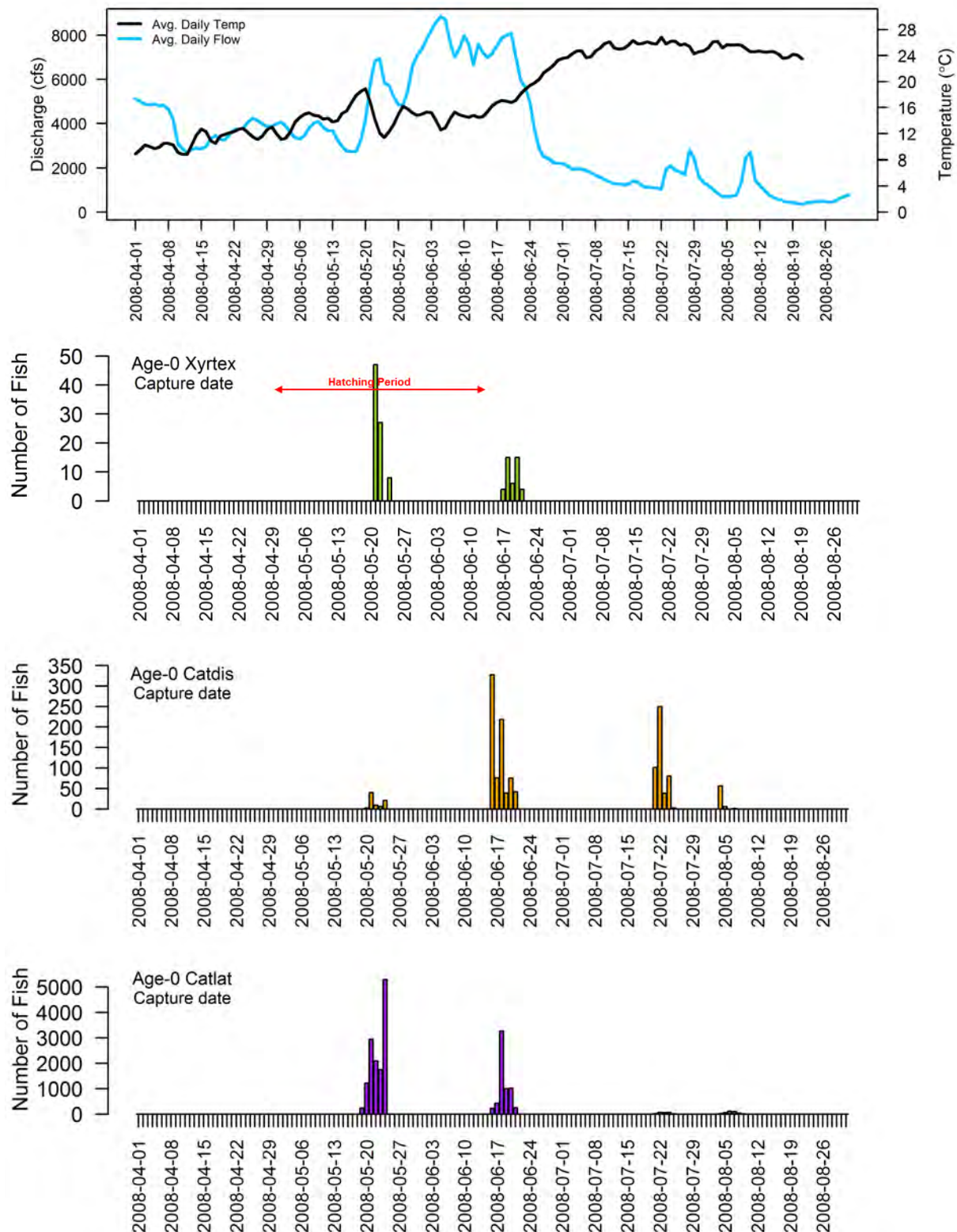
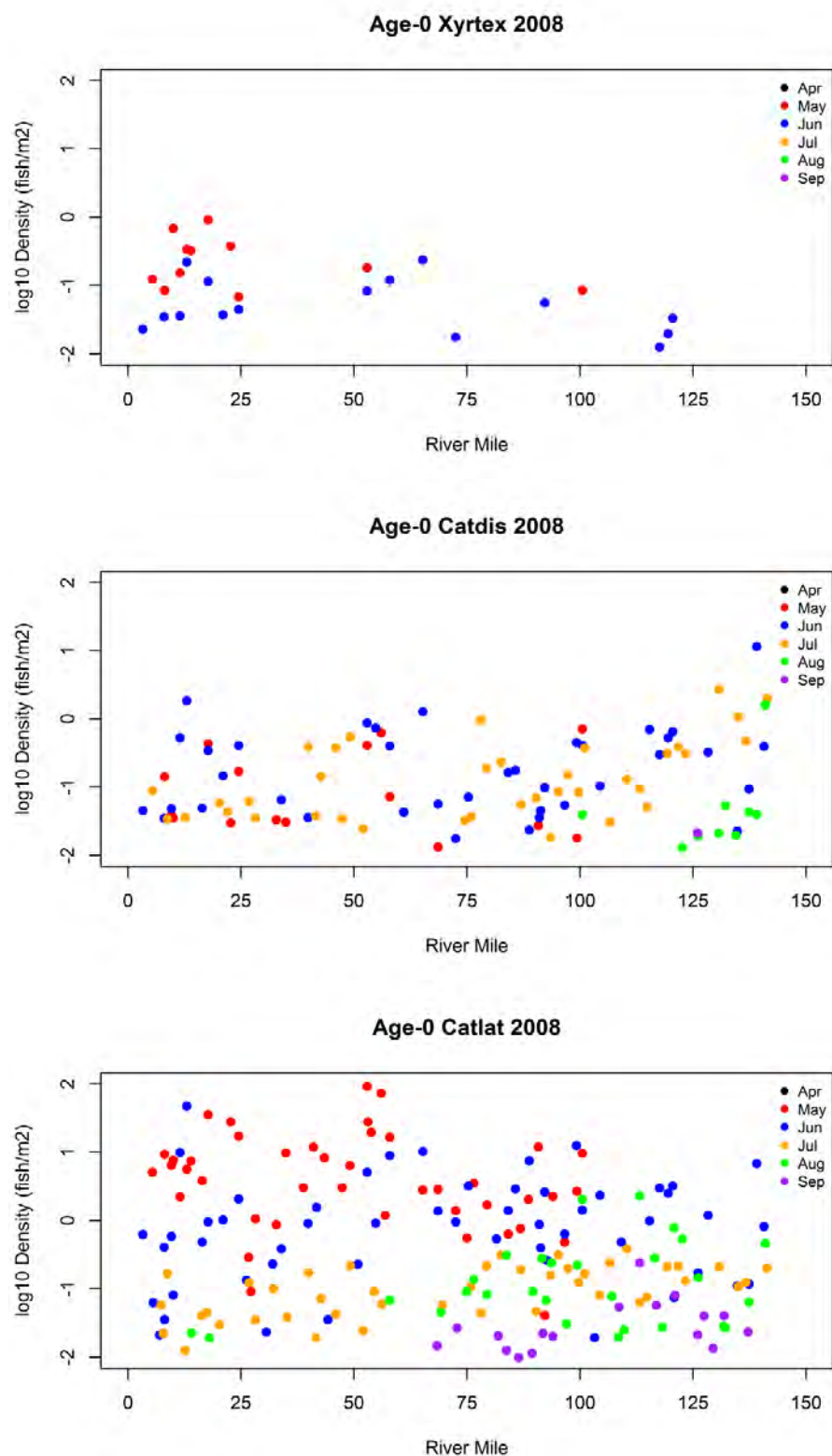
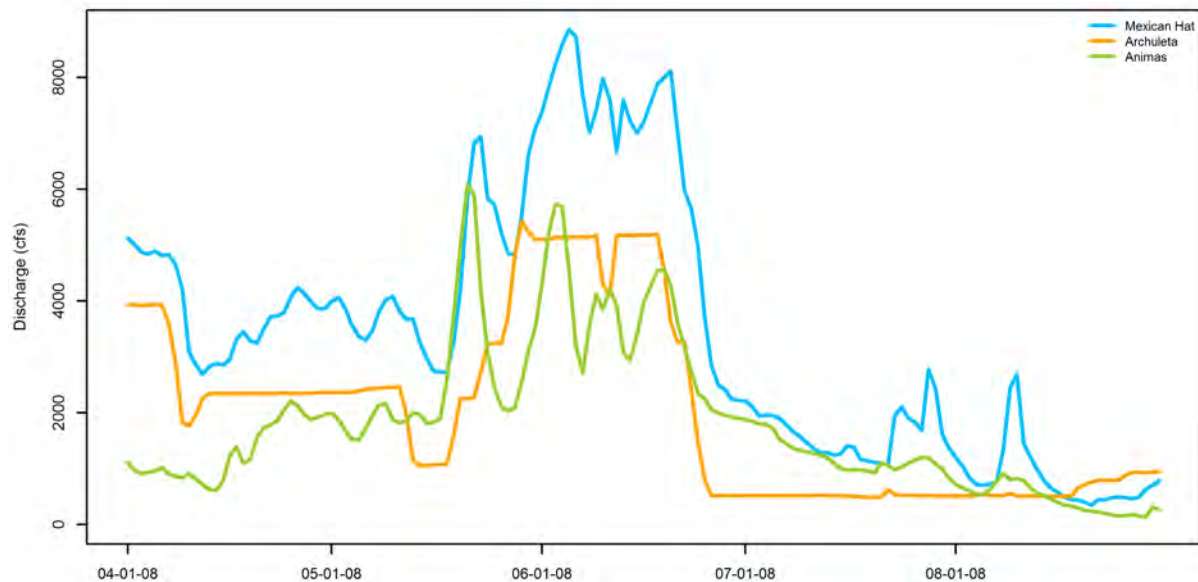


Figure A-21. Capture data for Razorback Sucker, Bluehead Sucker and Flannelmouth Sucker larvae, along with average daily temperature and average daily flow for the San Juan River at Mexican Hat, 2008.

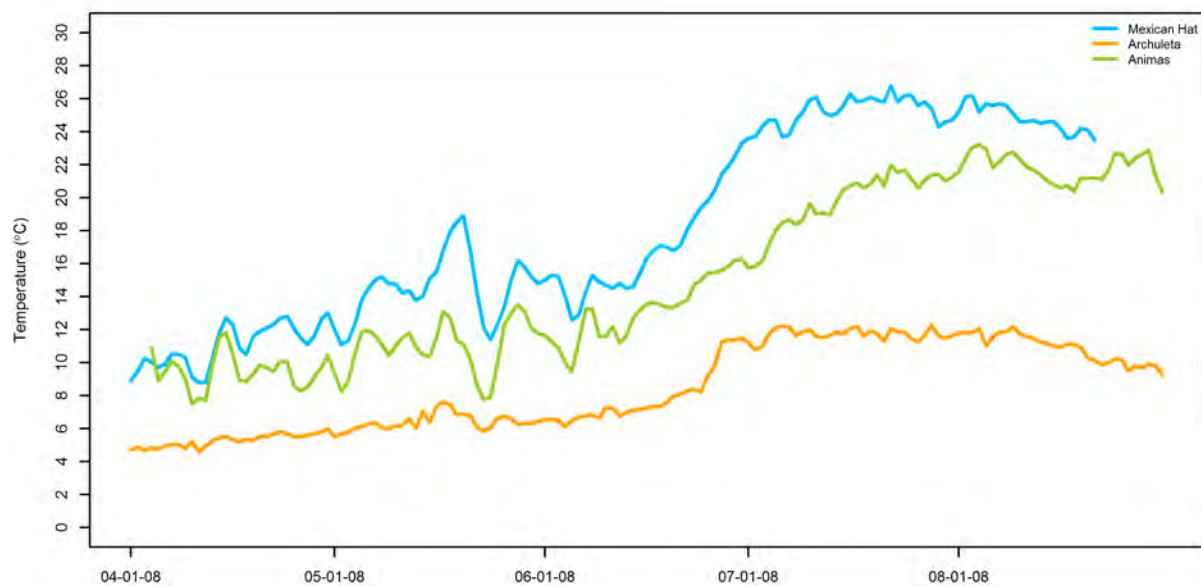


**Figure A-22. Months and locations in which Razorback Sucker, Bluehead Sucker and Flannelmouth Sucker larvae were captured, 2008.**





**Figure A-23. Average daily flow for the San Juan River at Archuleta and Mexican Hat and the Animas River at its confluence with the San Juan River, 2008.**



**Figure A-24. Average daily temperature for the San Juan River at Archuleta and Mexican Hat and the Animas River at its confluence with the San Juan River, 2008.**

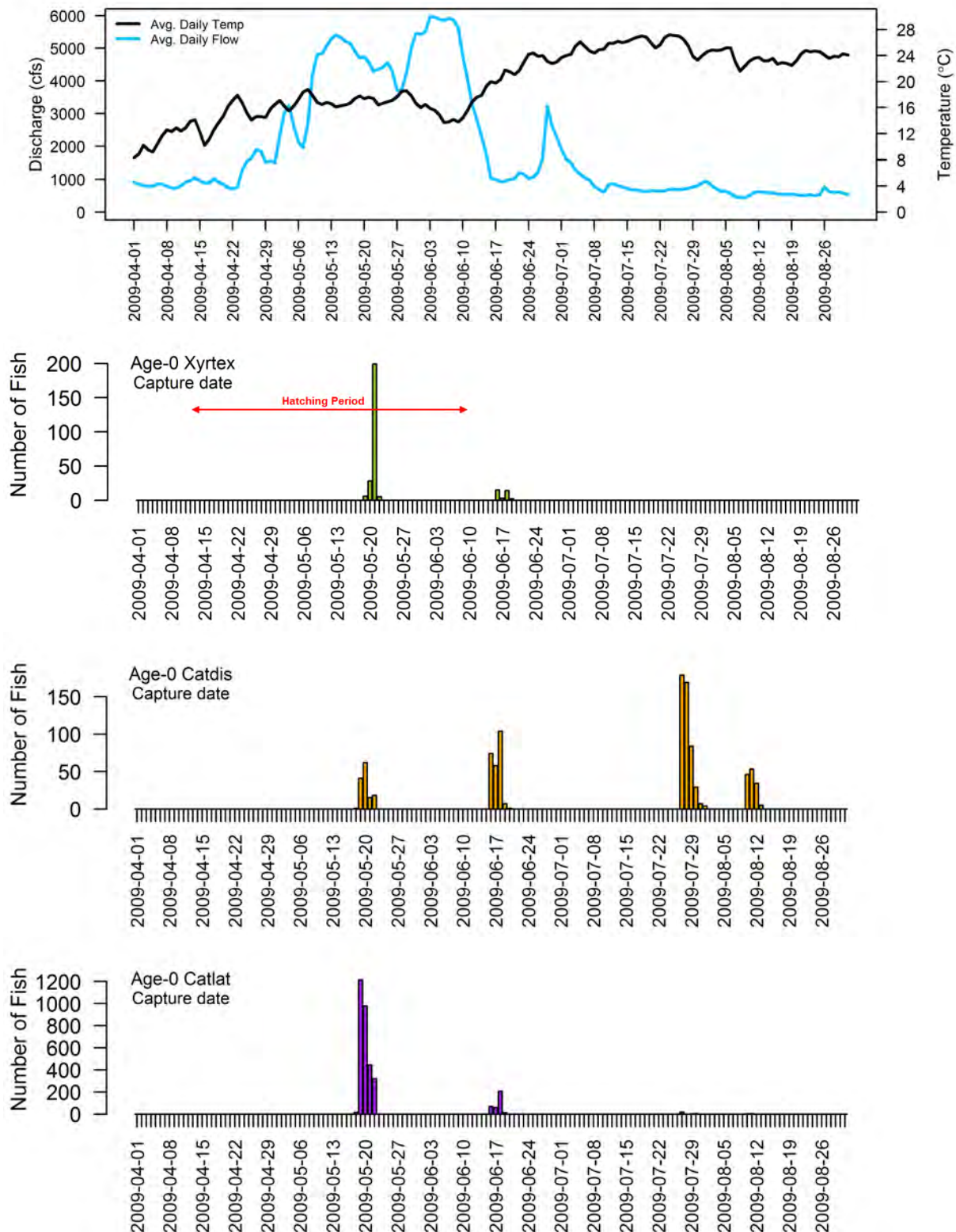
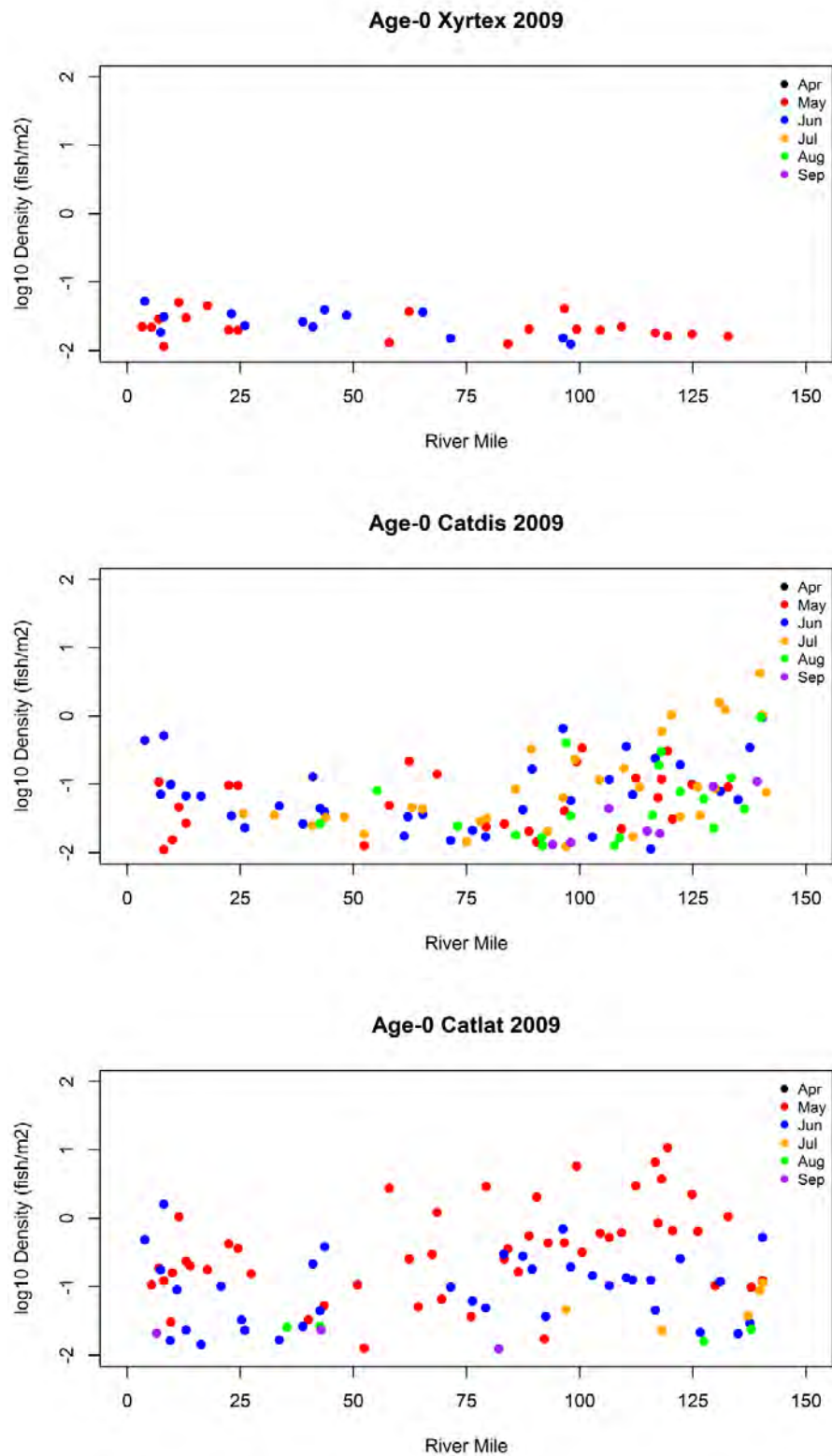
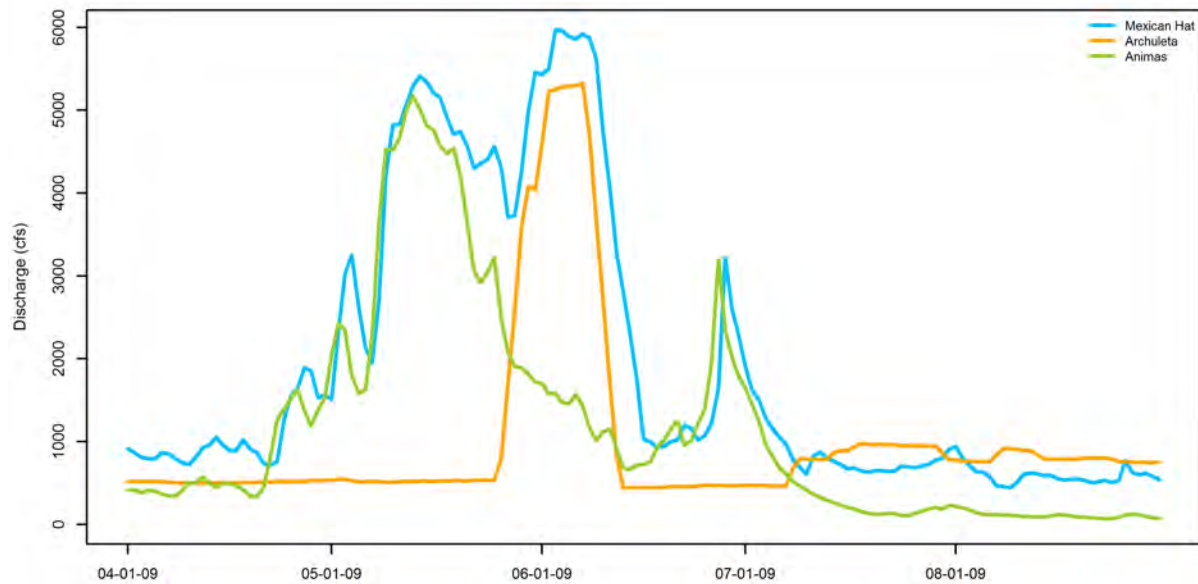


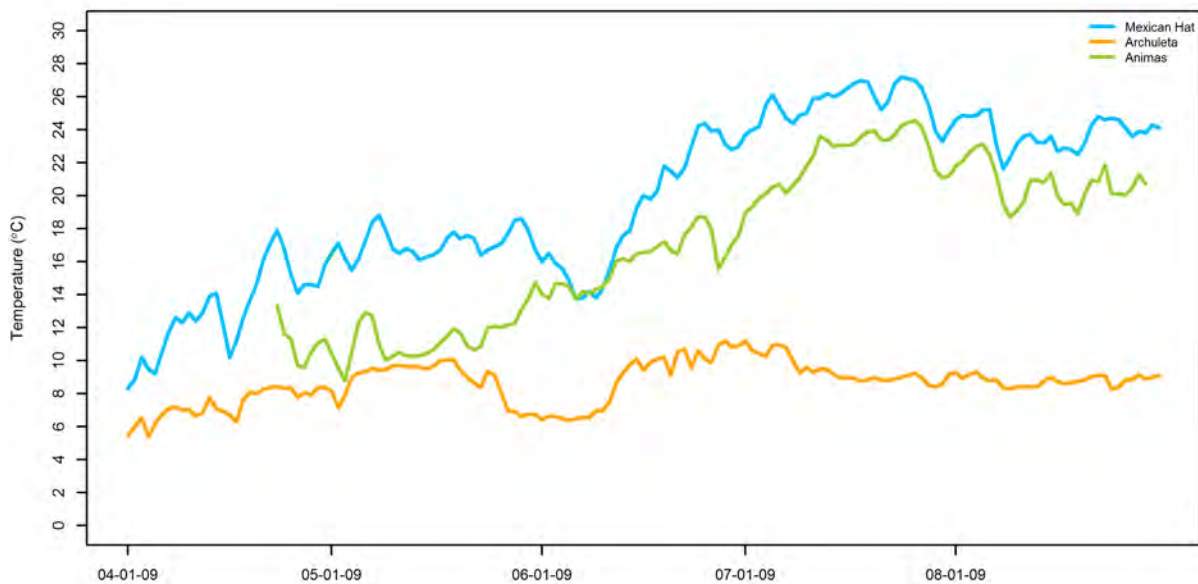
Figure A-25. Capture data for Razorback Sucker, Bluehead Sucker and Flannelmouth Sucker larvae, along with average daily temperature and average daily flow for the San Juan River at Mexican Hat, 2009.



**Figure A-26. Months and locations in which Razorback Sucker, Bluehead Sucker and Flannelmouth Sucker larvae were captured, 2009.**



**Figure A-27. Average daily flow for the San Juan River at Archuleta and Mexican Hat and the Animas River at its confluence with the San Juan River, 2009.**



**Figure A-28. Average daily temperature for the San Juan River at Archuleta and Mexican Hat and the Animas River at its confluence with the San Juan River, 2009.**



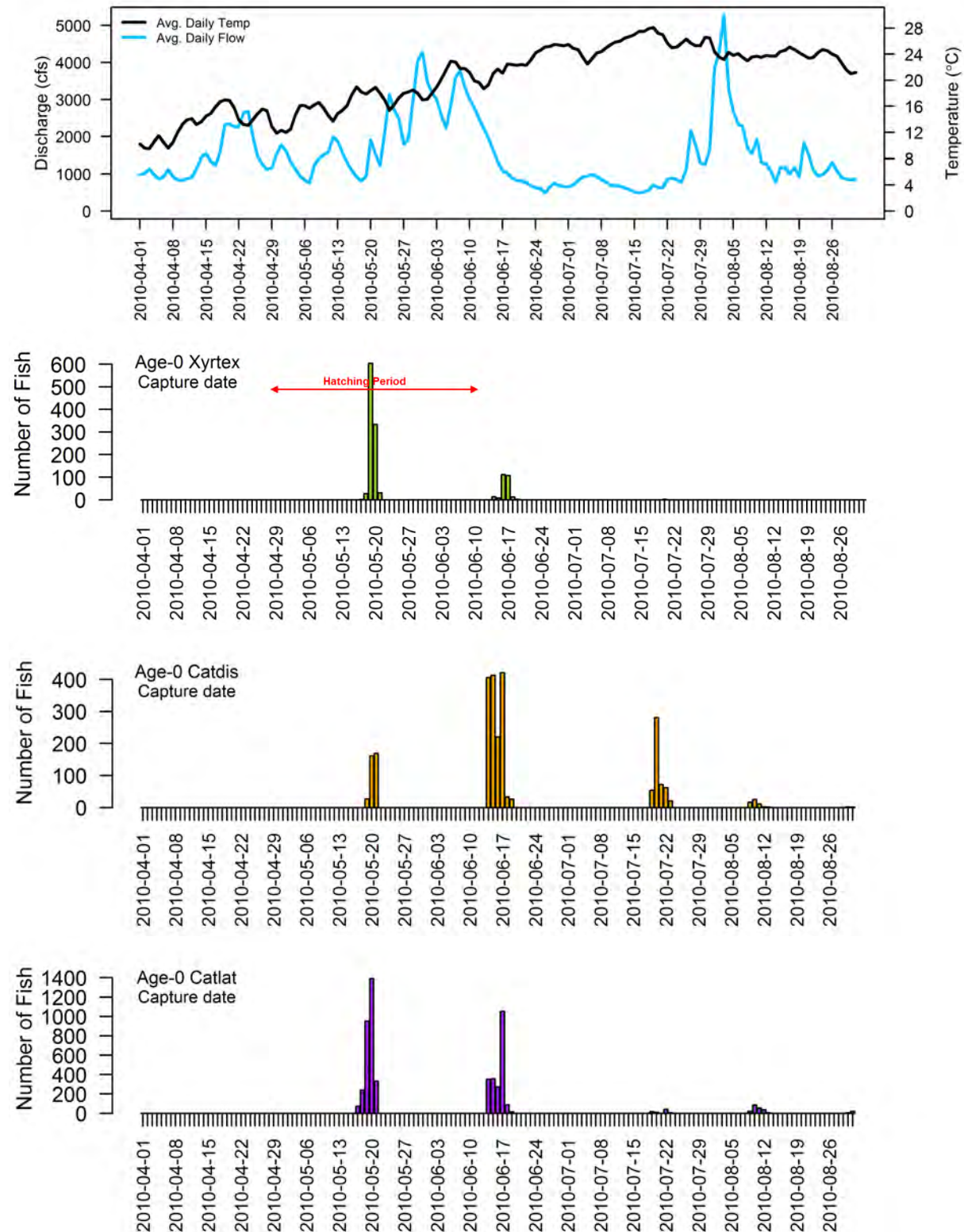
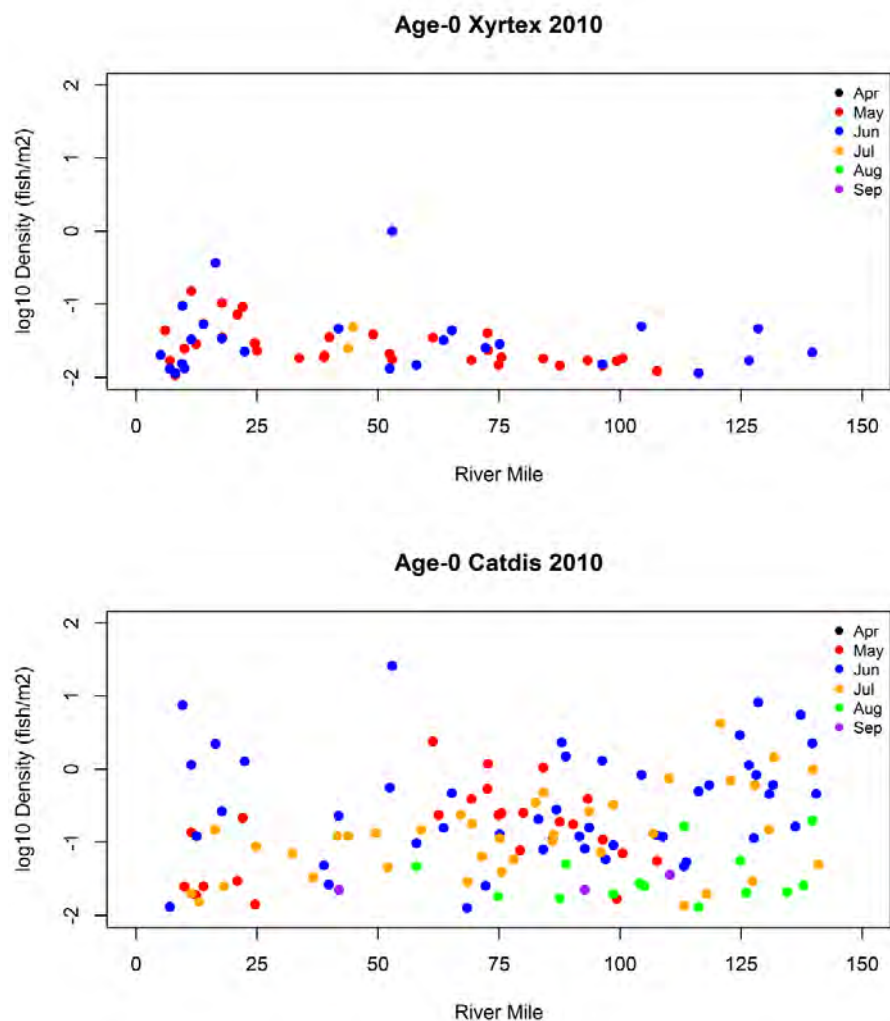
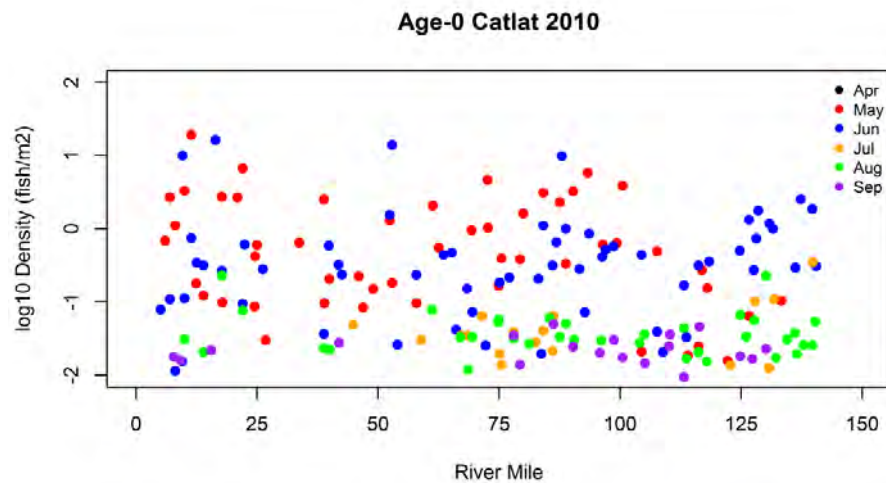
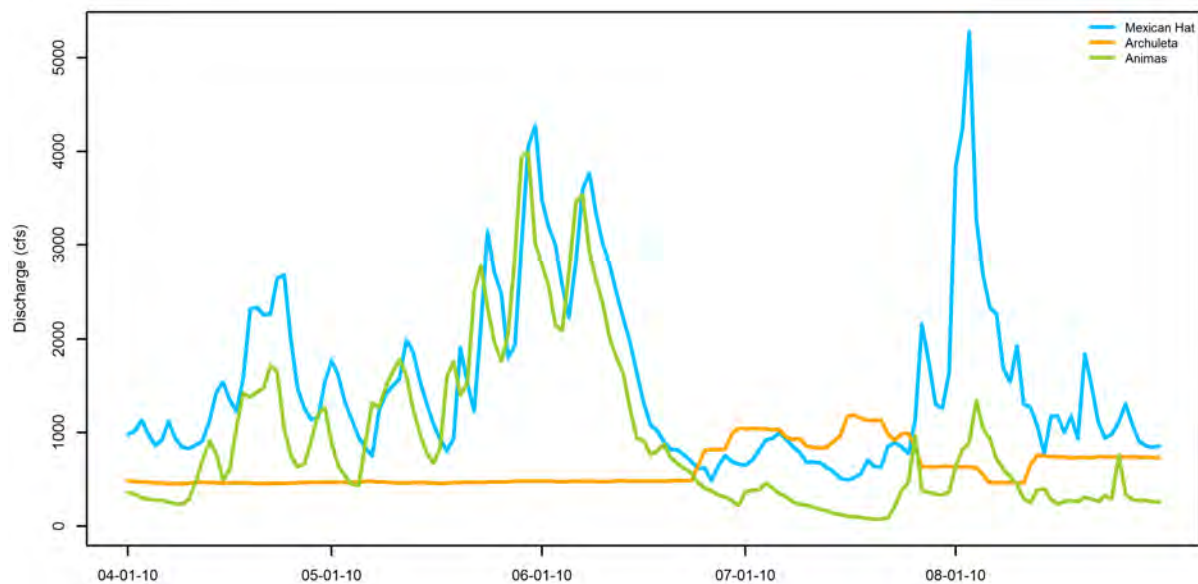


Figure A-29. Capture data for Razorback Sucker, Bluehead Sucker and Flannelmouth Sucker larvae, along with average daily temperature and average daily flow for the San Juan River at Mexican Hat, 2010.

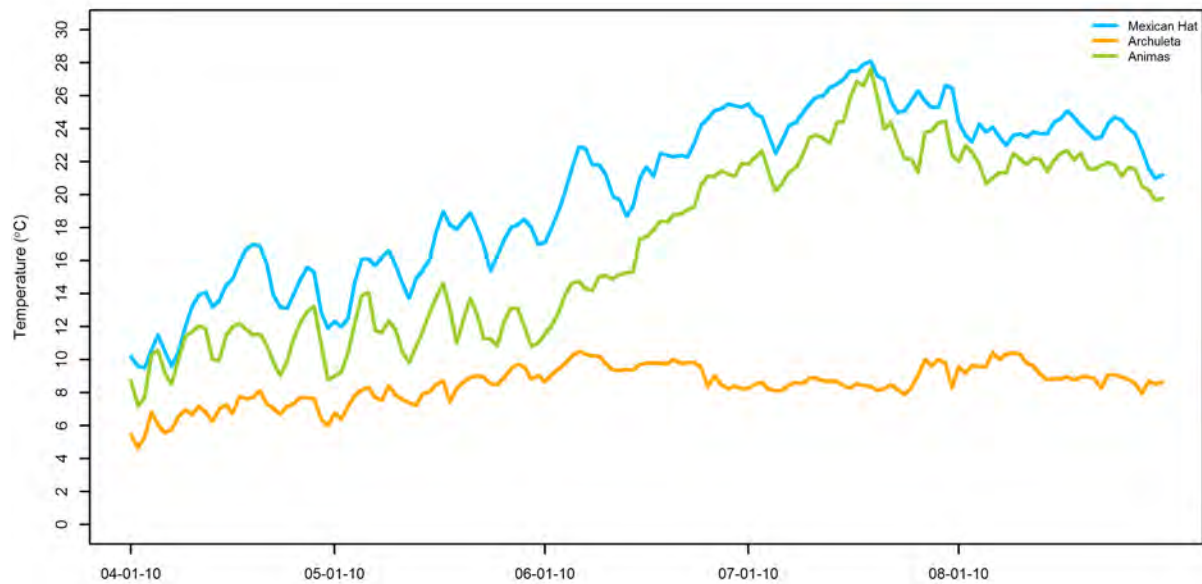




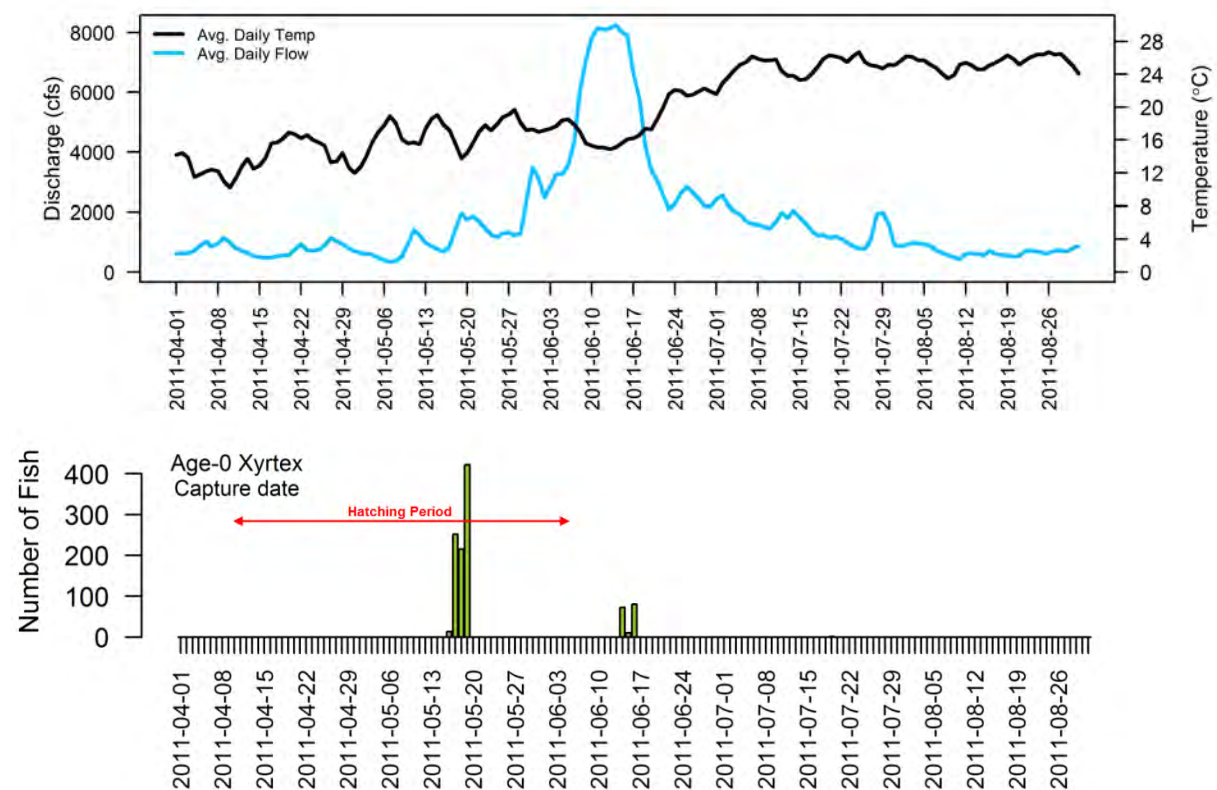
**Figure A-30. Months and locations in which Razorback Sucker, Bluehead Sucker and Flannelmouth Sucker larvae were captured, 2010.**



**Figure A-31. Average daily flow for the San Juan River at Archuleta and Mexican Hat and the Animas River at its confluence with the San Juan River, 2010.**



**Figure A-32. Average daily temperature for the San Juan River at Archuleta and Mexican Hat and the Animas River at its confluence with the San Juan River, 2010.**





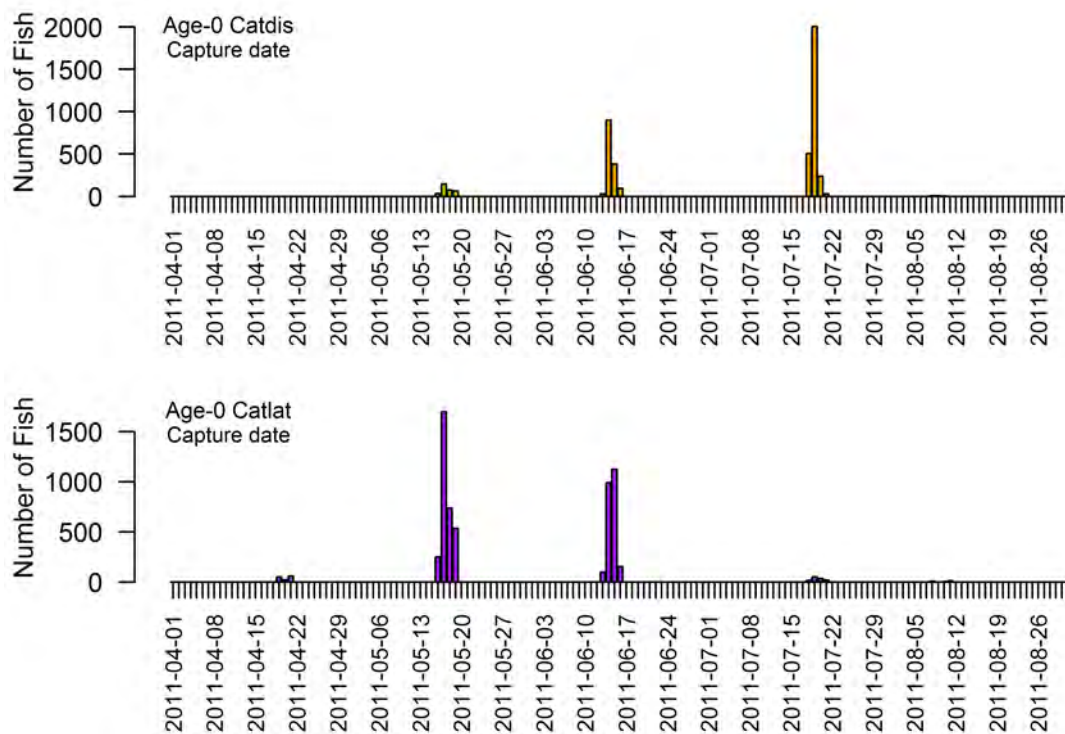
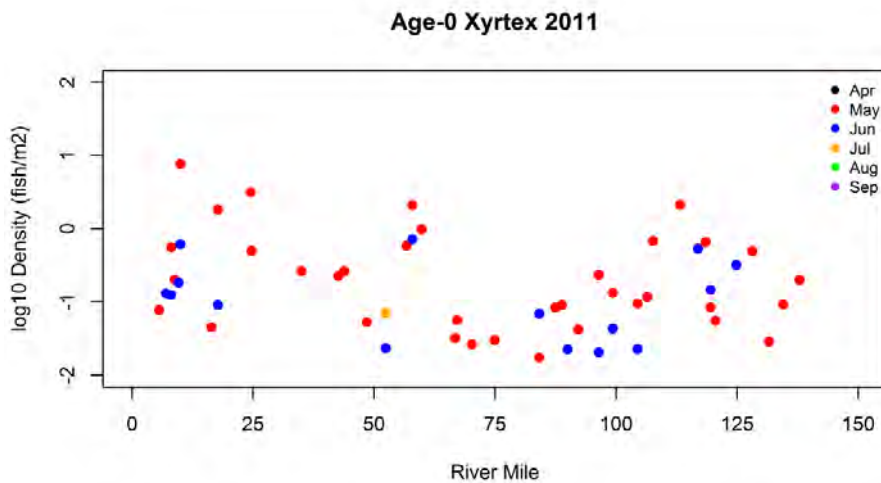
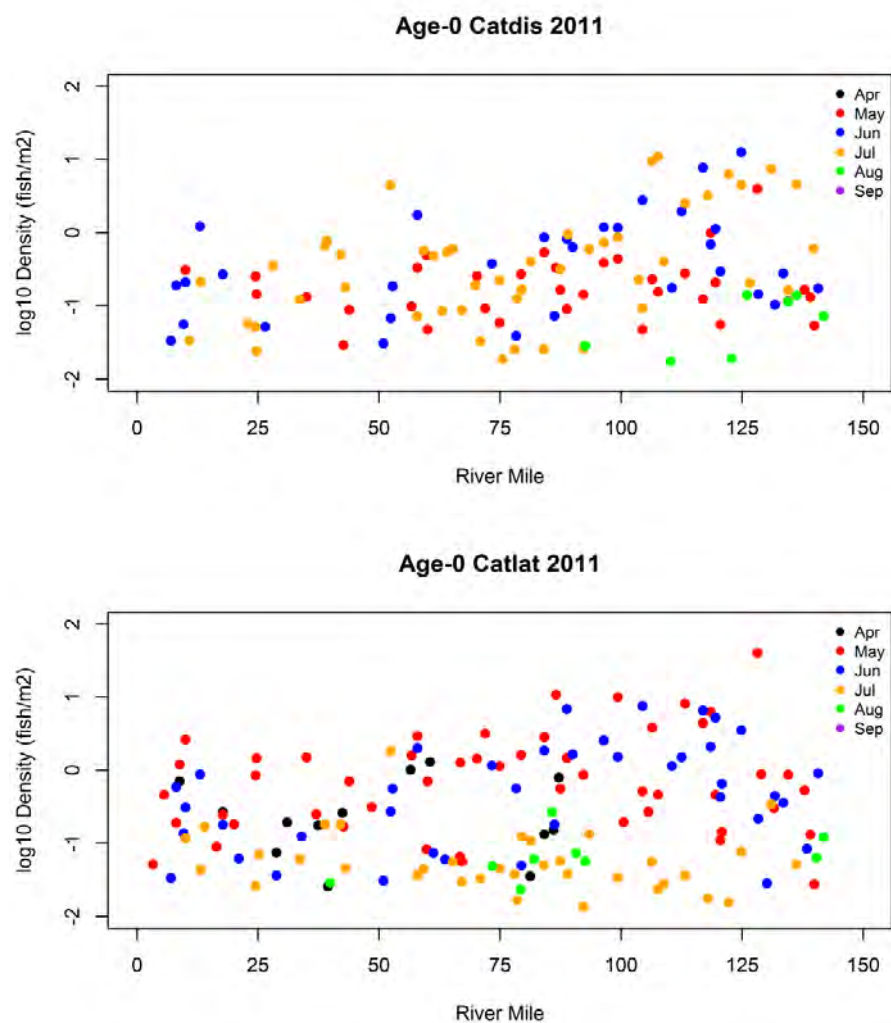
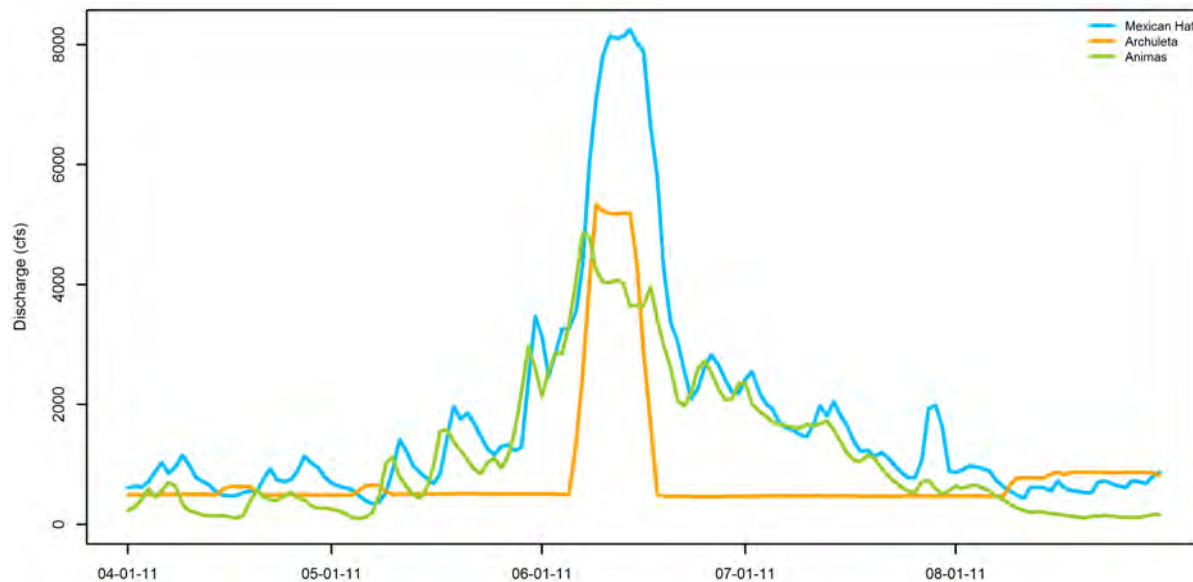


Figure A-33. Capture data for Razorback Sucker, Bluehead Sucker and Flannelmouth Sucker larvae, along with average daily temperature and average daily flow for the San Juan River at Mexican Hat, 2011.

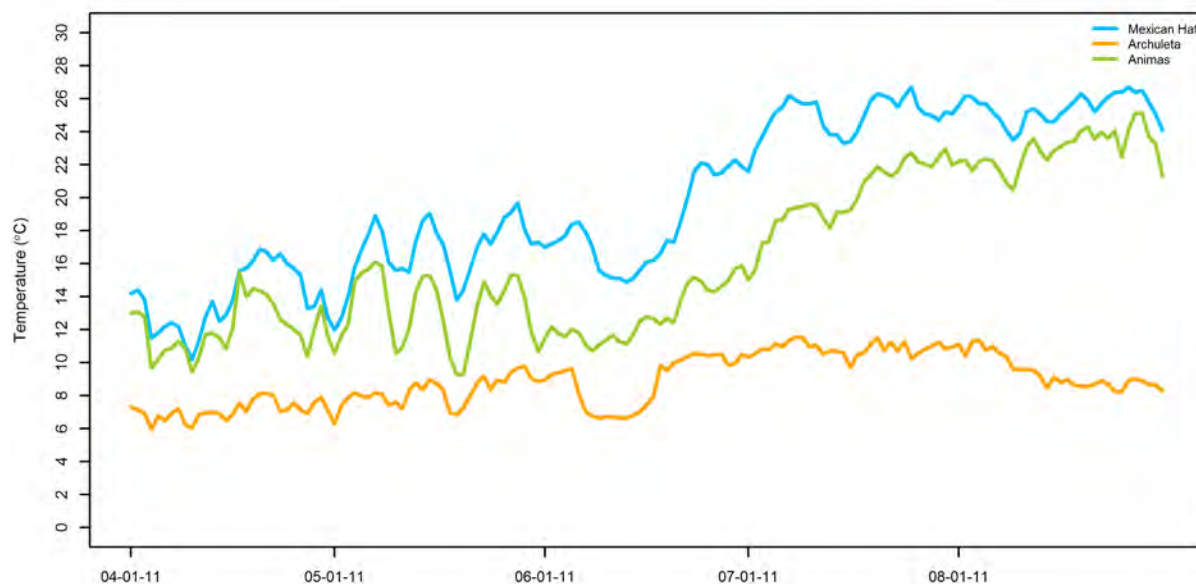




**Figure A-34. Months and locations in which Razorback Sucker, Bluehead Sucker and Flannelmouth Sucker larvae were captured, 2011.**



**Figure A-35. Average daily flow for the San Juan River at Archuleta and Mexican Hat and the Animas River at its confluence with the San Juan River, 2011.**



**Figure A-36. Average daily temperature for the San Juan River at Archuleta and Mexican Hat and the Animas River at its confluence with the San Juan River, 2011.**

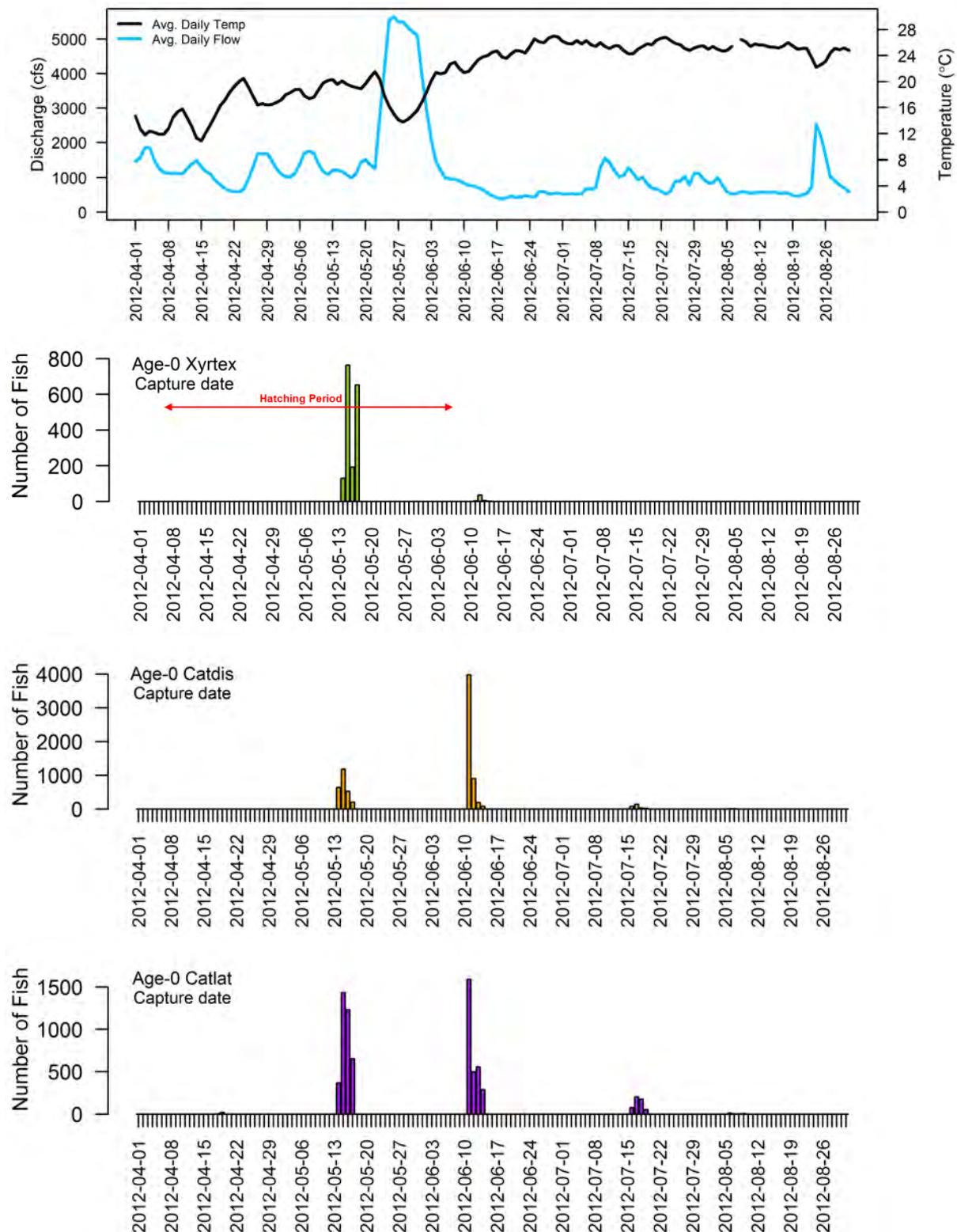
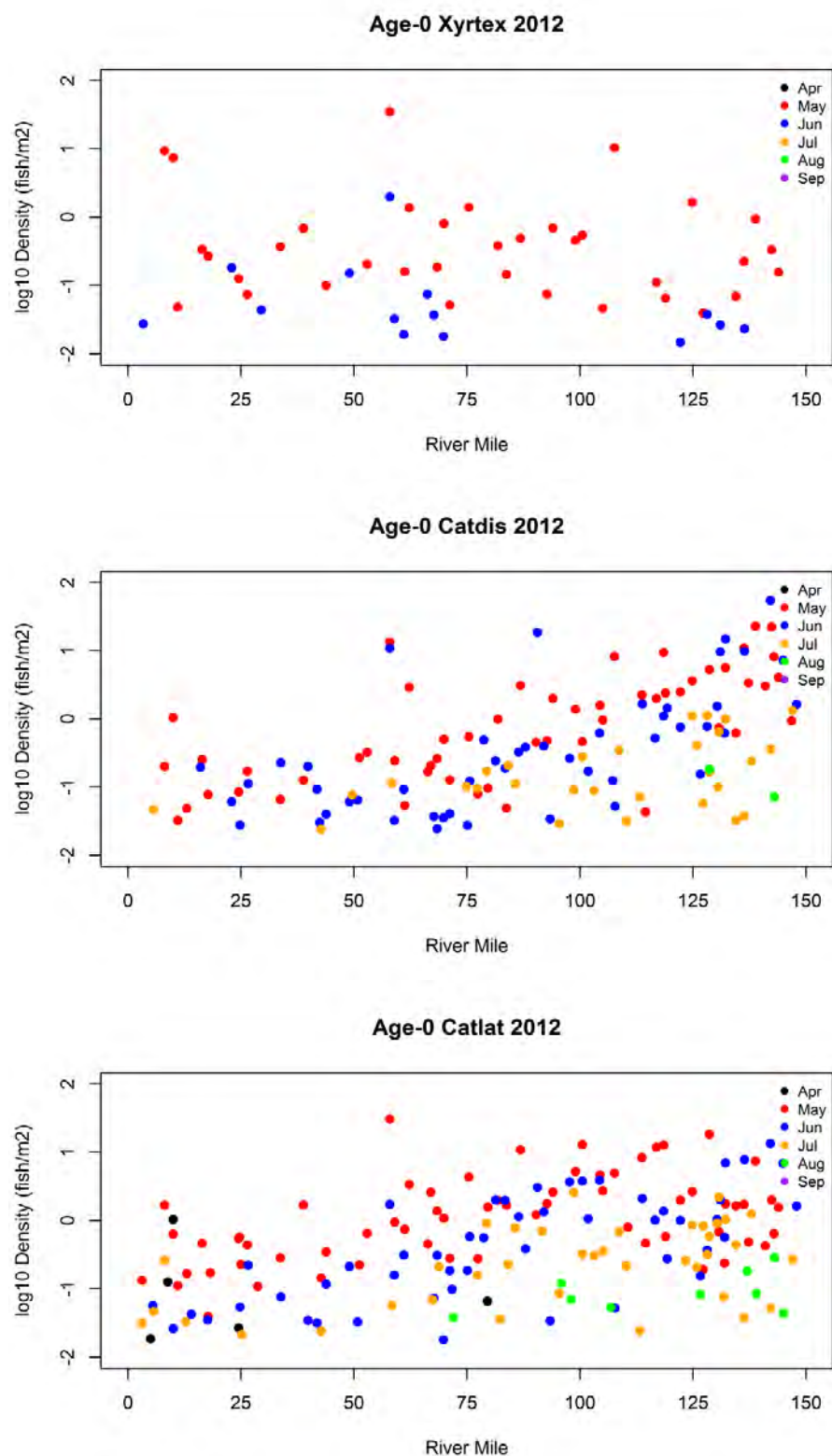
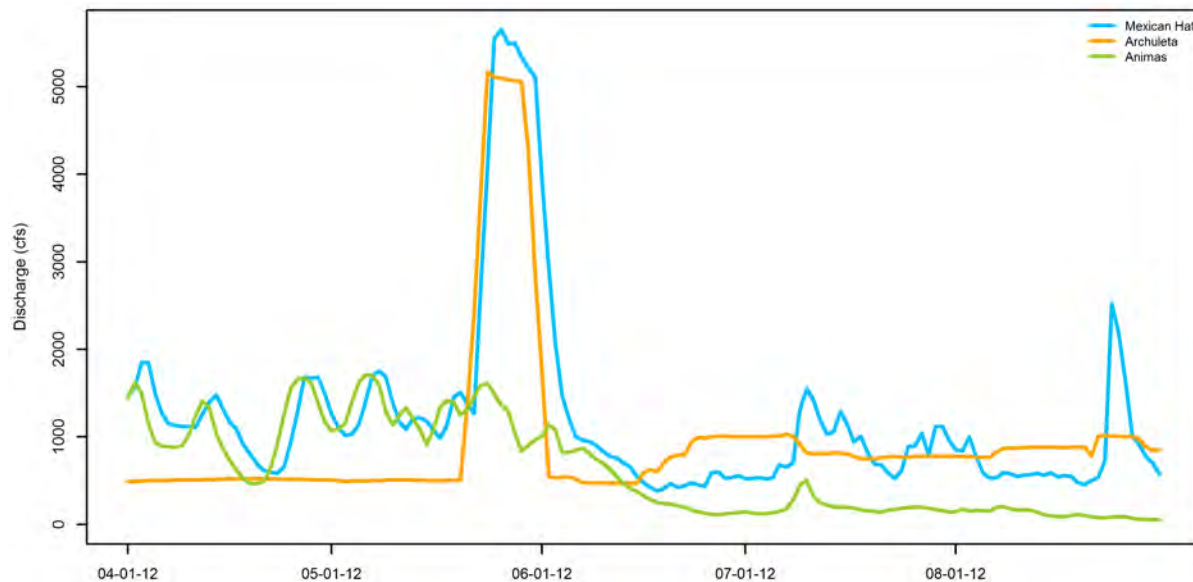


Figure A-37. Capture data for Razorback Sucker, Bluehead Sucker and Flannelmouth Sucker larvae, along with average daily temperature and average daily flow for the San Juan River at Mexican Hat, 2012.

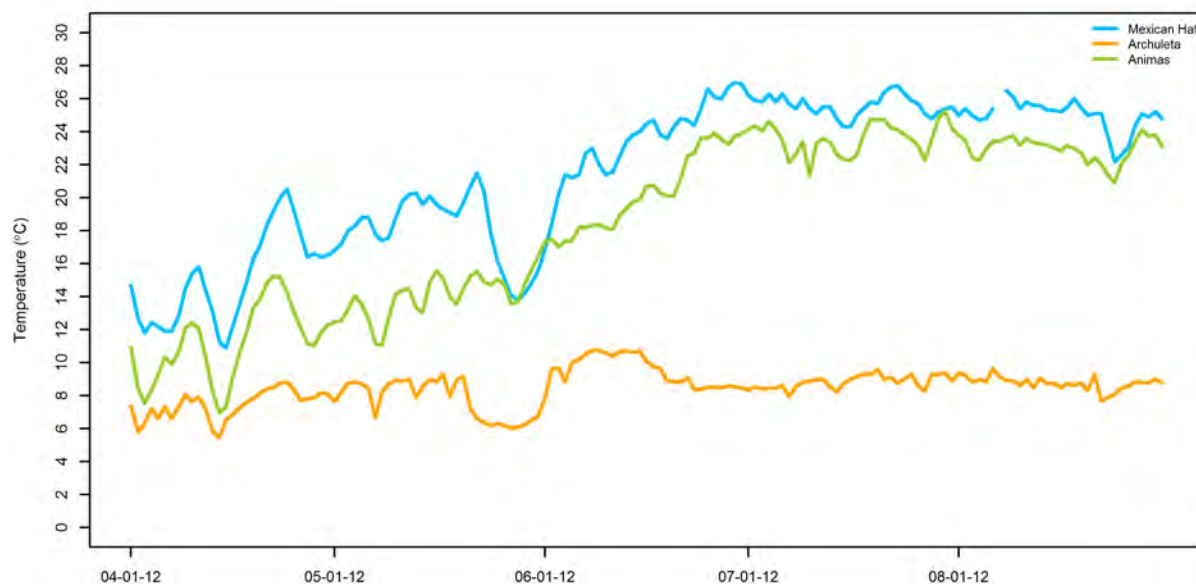




**Figure A-38. Months and locations in which Razorback Sucker, Bluehead Sucker and Flannelmouth Sucker larvae were captured, 2012.**



**Figure A-39. Average daily flow for the San Juan River at Archuleta and Mexican Hat and the Animas River at its confluence with the San Juan River, 2012.**



**Figure A-40. Average daily temperature for the San Juan River at Archuleta and Mexican Hat and the Animas River at its confluence with the San Juan River, 2012.**

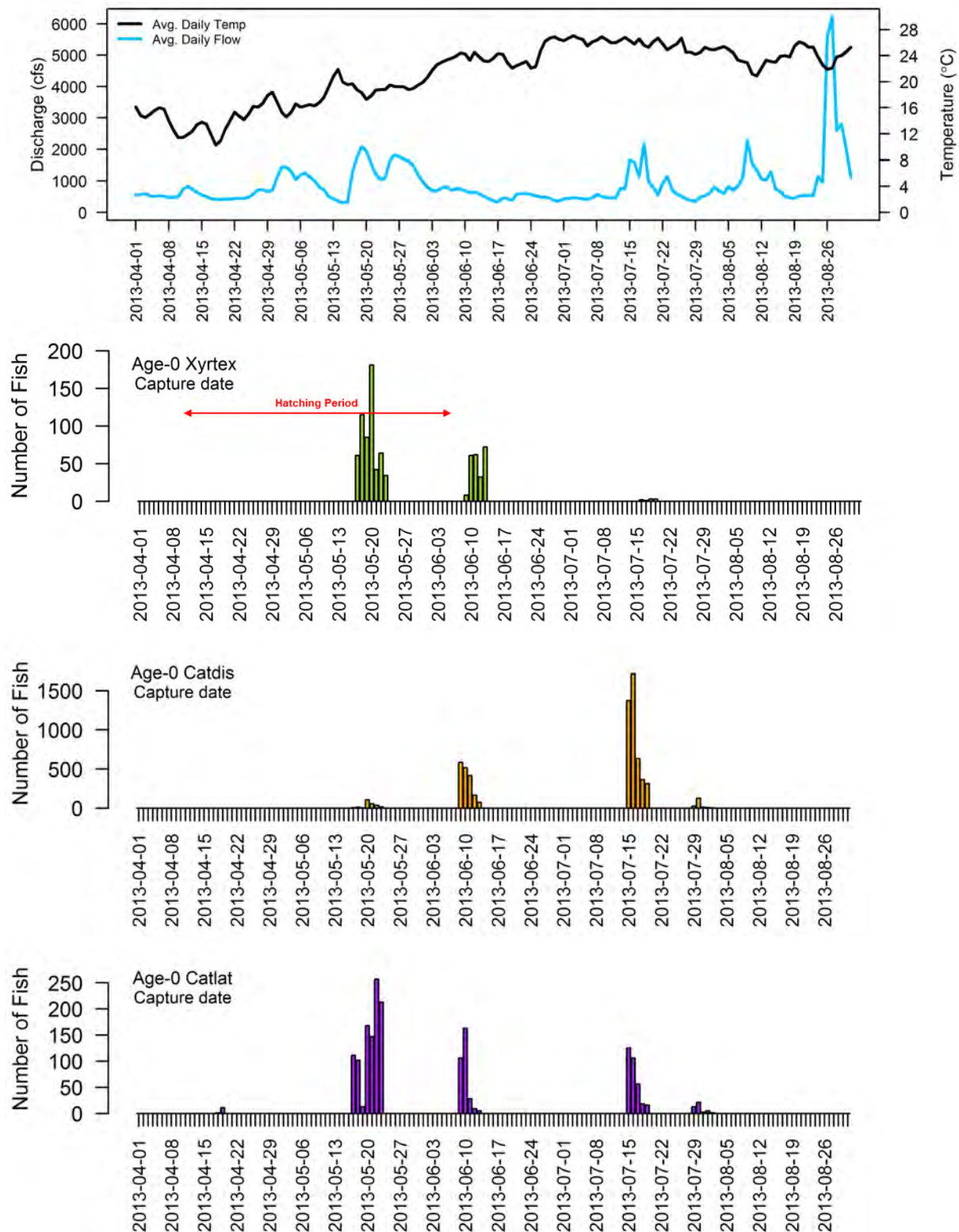
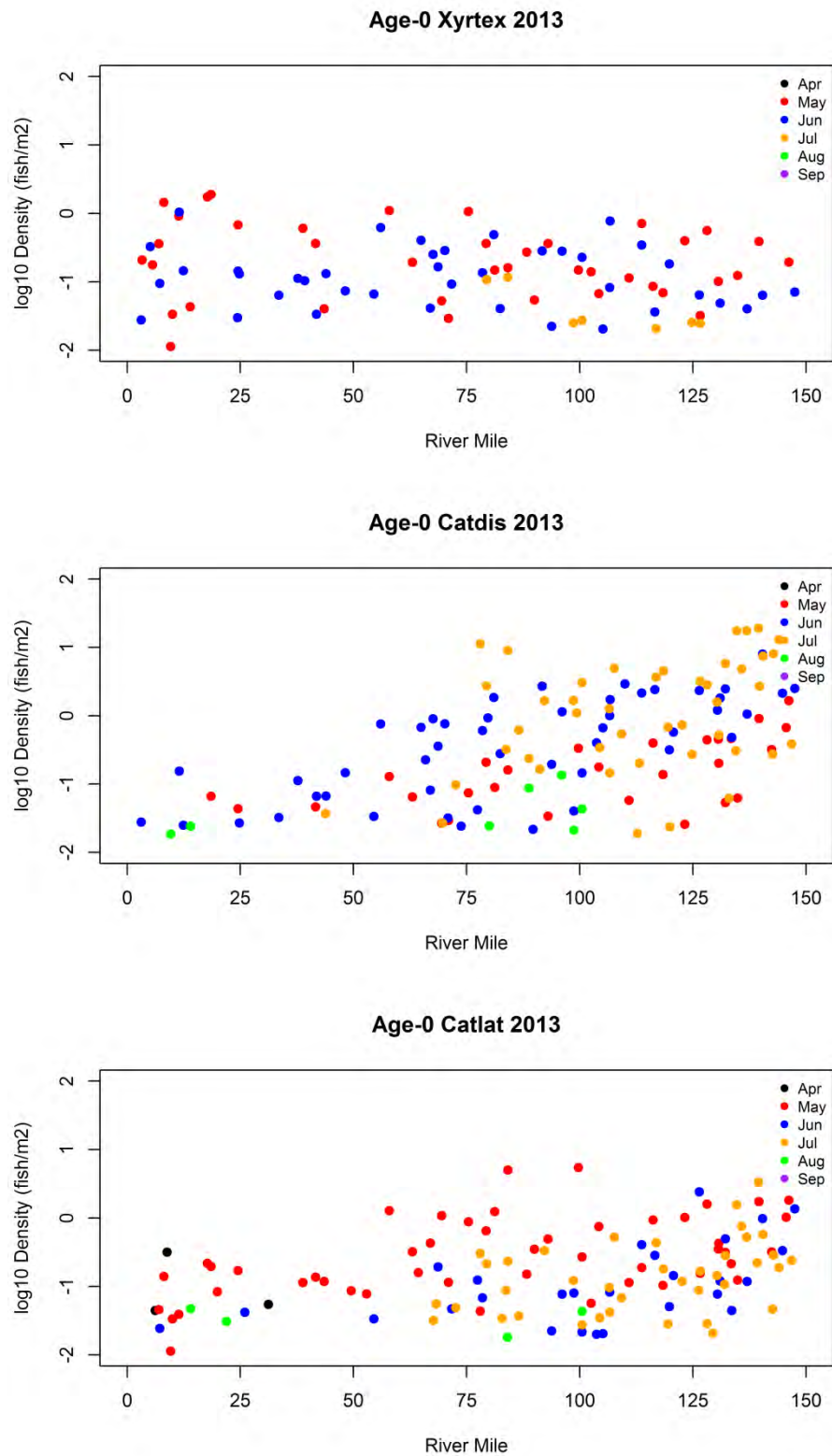
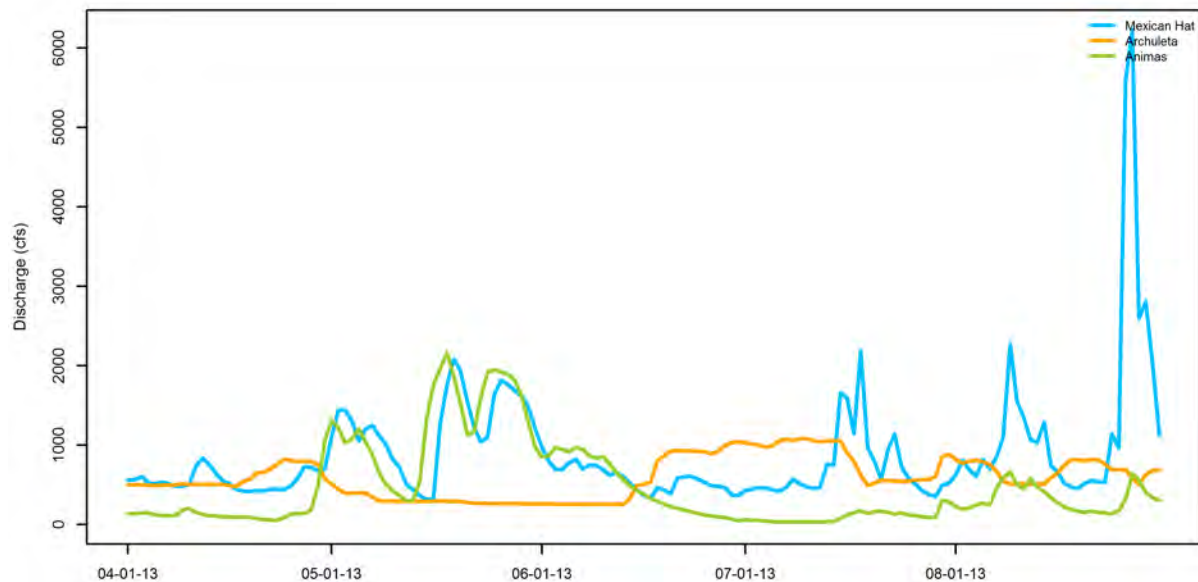


Figure A-41. Capture data for Razorback Sucker, Bluehead Sucker and Flannelmouth Sucker larvae, along with average daily temperature and average daily flow for the San Juan River at Mexican Hat, 2013.

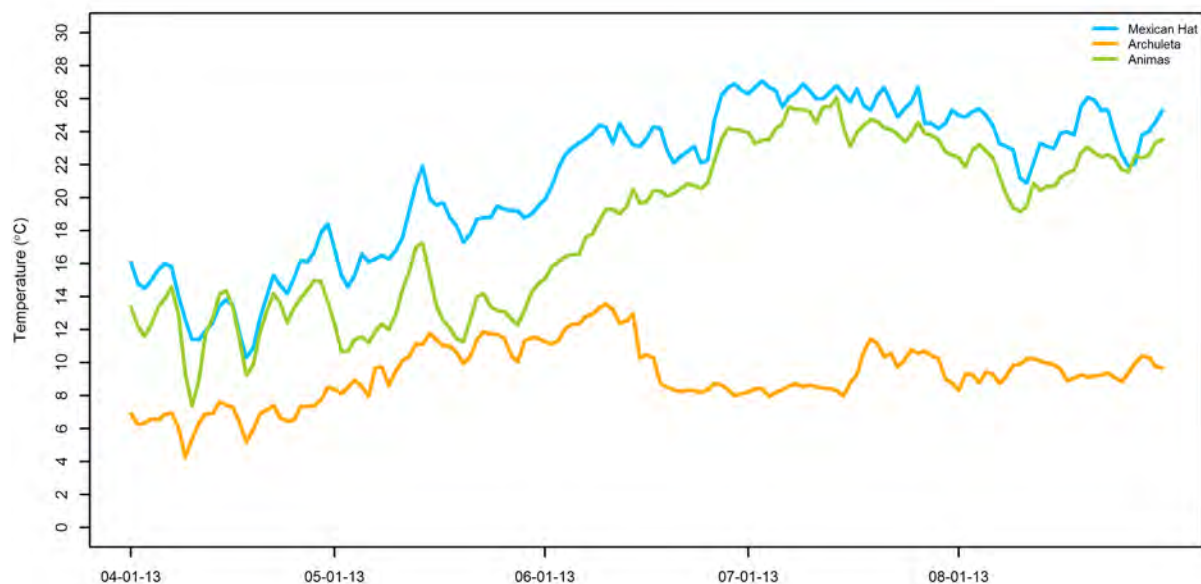


**Figure A-42. Months and locations in which Razorback Sucker, Bluehead Sucker and Flannelmouth Sucker larvae were captured, 2013.**





**Figure A-43. Average daily flow for the San Juan River at Archuleta and Mexican Hat and the Animas River at its confluence with the San Juan River, 2013.**



**Figure A-44. Average daily temperature for the San Juan River at Archuleta and Mexican Hat and the Animas River at its confluence with the San Juan River, 2013.**

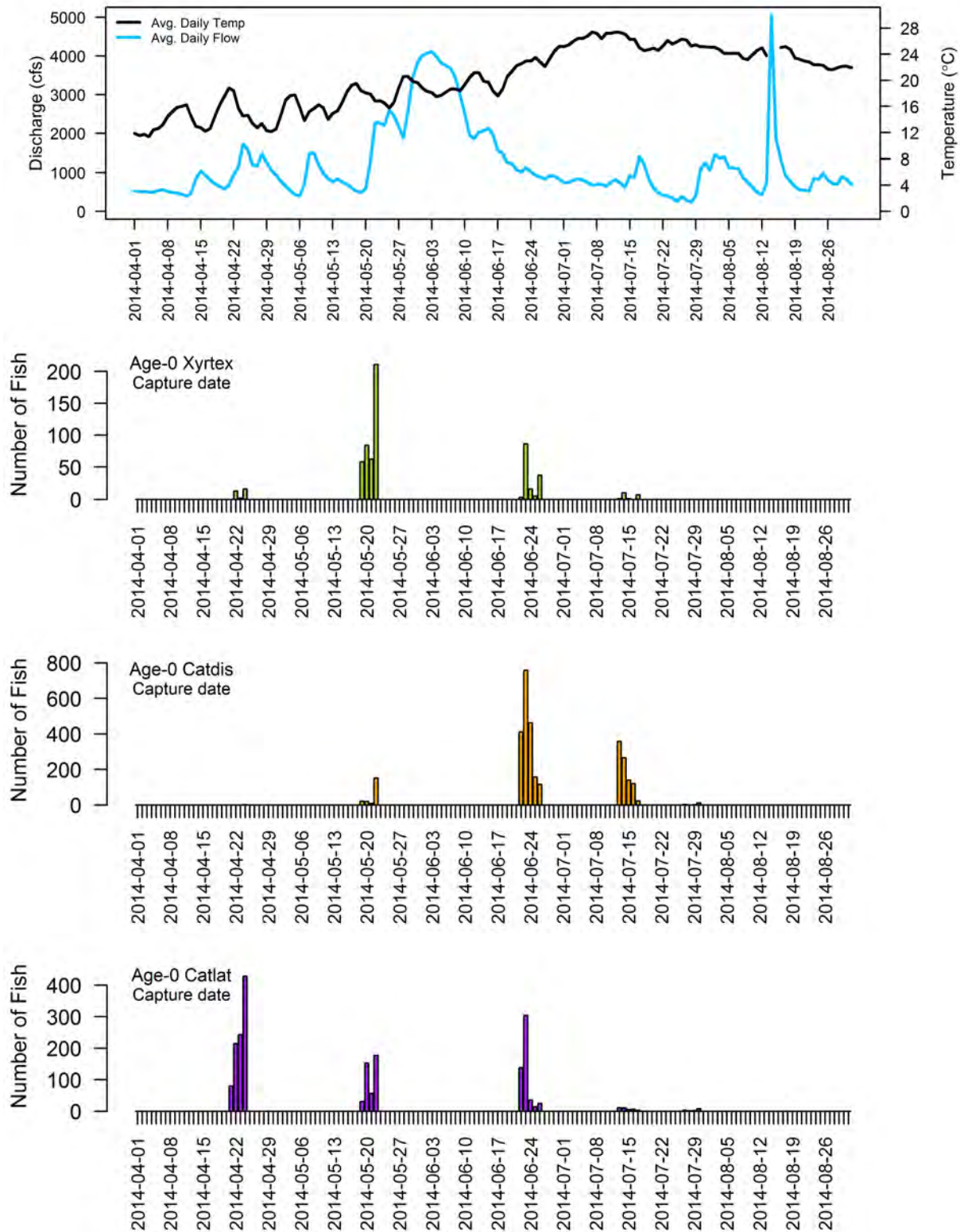
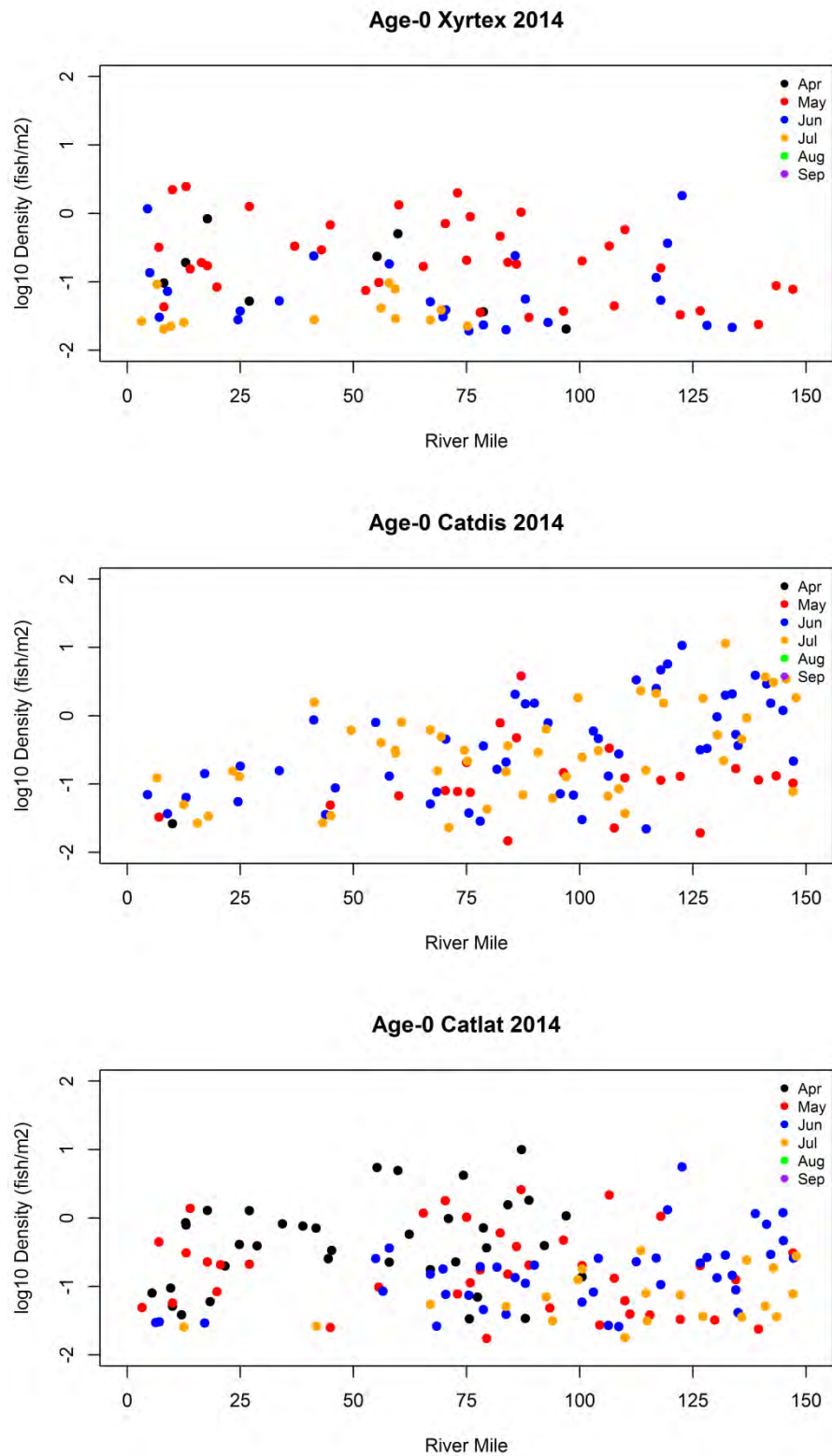
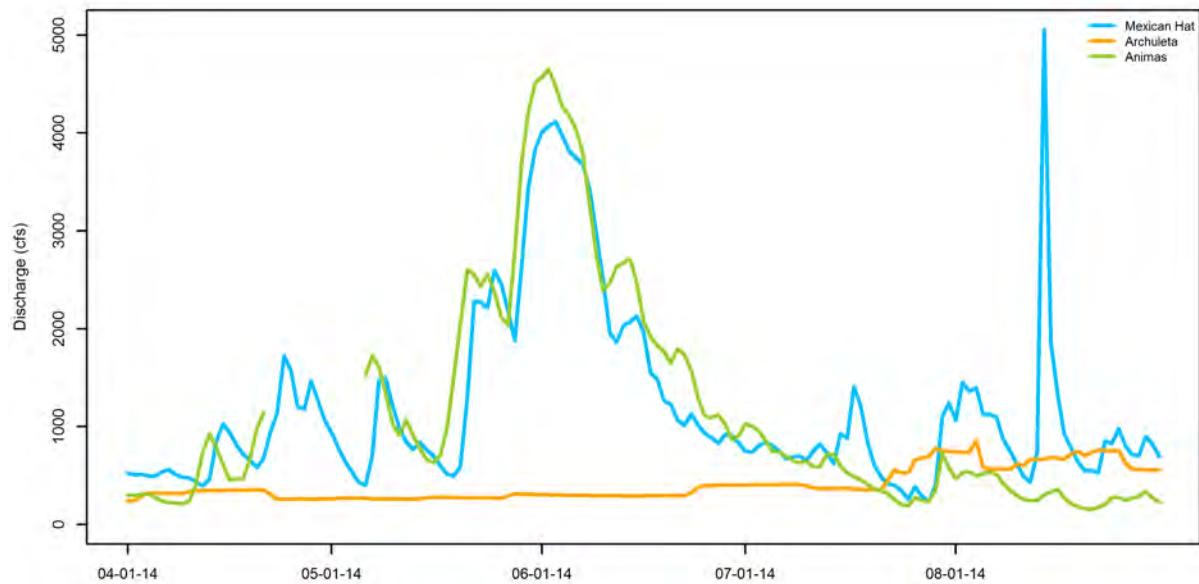


Figure A-45. Capture data for Razorback Sucker, Bluehead Sucker and Flannelmouth Sucker larvae, along with average daily temperature and average daily flow for the San Juan River at Mexican Hat, 2014.

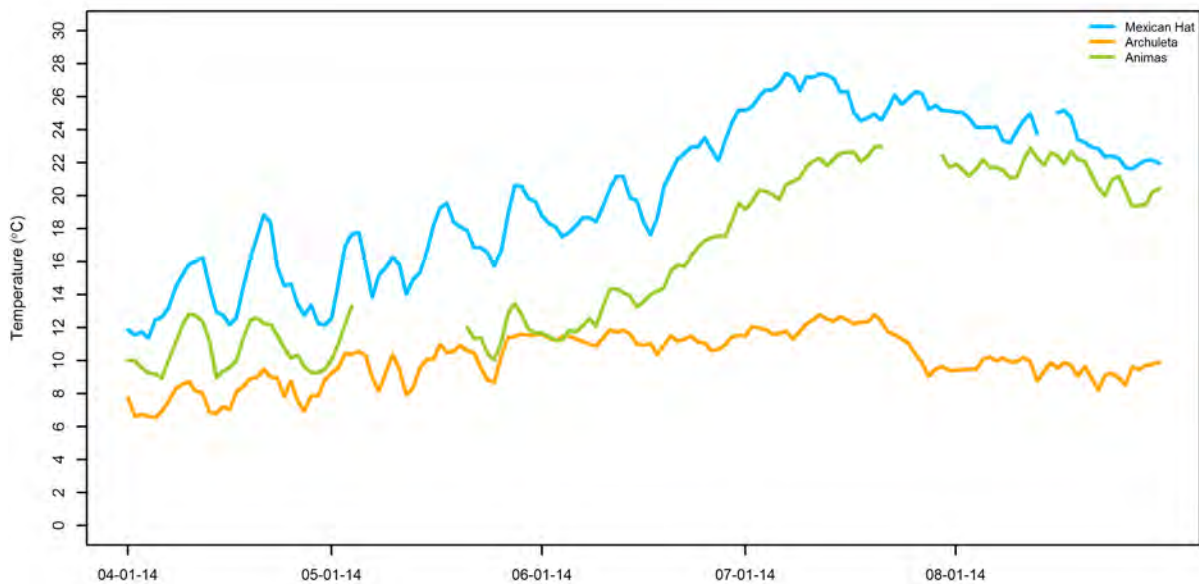


**Figure A-46. Months and locations in which Razorback Sucker, Bluehead Sucker and Flannelmouth Sucker larvae were captured, 2014.**





**Figure A-47. Average daily flow for the San Juan River at Archuleta and Mexican Hat and the Animas River at its confluence with the San Juan River, 2014.**



**Figure A-48. Average daily temperature for the San Juan River at Archuleta and Mexican Hat and the Animas River at its confluence with the San Juan River, 2014.**